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PETROGRAPHIC STUDY OF PORTLAND CEMENT

BY R. J. COLONY.

The observations recorded in this paper are the result of an attempt to apply ordinary petrographic methods to the study of a defective concrete, with the object of ascertaining the cause of disintegration, all other and usual methods having failed. When thin sections of the concrete in question were examined, however, certain features presented themselves which seemed to render essential a preliminary study both of Portland cement clinker, and of the action of gaging water on cement, neat and also mixed with aggregate, in order that these features might be correctly interpreted.

Unground clinker, cement made from it, the action of water on such cement, and the cause of the subsequent hardening of set cement have been studied by numerous investigators, who have used both chemical and microscopic methods; the conclusions drawn as a result of these investigations, when applied to the problem in hand, have not sufficed to solve it. The chief difficulty in the petrographic study of material of this nature lies not only in the exceedingly fine texture of the cement, but also in the uncertainty of correctly identifying the crystalline and other products of hydration, because of such texture, and in properly interpreting the structures presented to view.

Portland cement clinker results from the strong calcination of properly proportioned mixtures of calcareous and argillaceous materials; owing to the high temperature to which these mixtures are exposed incipient fusion results, and pos-

sibly a solid solution is formed, from which certain constituents crystallize during the cooling of the clinker, in a manner somewhat similar to the crystallization of rock-forming minerals from an igneous magma; the analogy is not exact, however, because complete fusion of the clinker never occurs.

From a chemical and microscopic study LeChatelier [1] concludes that the components of cement clinker are themselves solid solutions, which, however, have sufficiently constant optical properties to permit of their identification in thin sections of the clinker.

Törnebohm [3] suggested the names Alit, Belit, Celit and Felit for these components. Richardson [2] prepared synthetically a series of clinkers in which the components were tri-calcium silicate and tri-calcium aluminate in varying proportions, and studied thin sections of them.

The net result of these investigations leads to the belief that Portland cement clinker consists of an aggregate of certain components of more or less definite characters, conceived to be solid solutions, or isomorphous mixtures, possessing optical properties and crystal habits of sufficient constancy to permit of their identification with certainty in thin sections. Since these components are solid solutions, and not definite compounds, their composition is not constant, but varies within the limits of solubility of the solute in each case; hence slight changes in composition and temperature of burning may result in varying proportions between the components mentioned, which in turn may affect the quality of the resulting cement.

In the specimens of clinker examined during the course of this investigation, only three of the constituents were identified; of these, alit and belit were dominant. Alit occurs in short stout, prisms, rounded at the ends, and in colorless polyhedral grains of moderately high refringence, weak birefringence, and containing numerous gas inclusions, judged to be carbon dioxide; the extinction of the prisms is essentially parallel, and the elongation is positive.

Belit occurs in granular aggregate, more or less greenish in color, with about the same refringence as that of alit, but stronger birefringence; gas inclusions are rare. Celit occurs

[1] Footnotes refer to the bibliography at the end of this paper.

interstitially between the alit and belit; it exhibits a wide range in color, varying from yellow, orange, red, to brown, and possesses a stronger birefringence than either alit or belit; but this also varies, being at times obscured by the color. Fig. 1 illustrates the habit and character of these components;

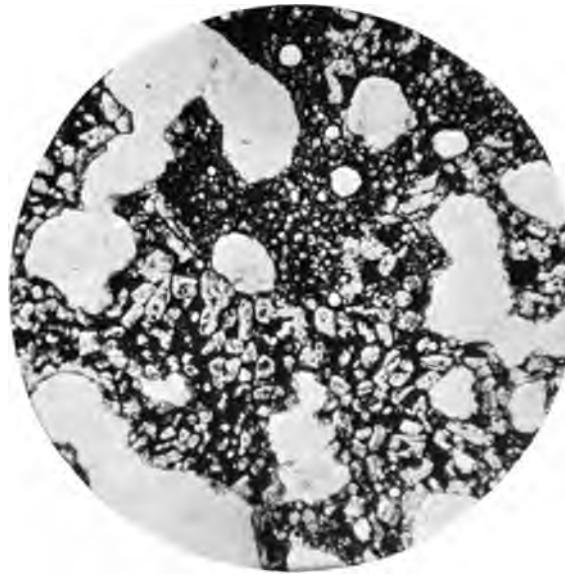

Fig. 1. Portland cement clinker; ordinary light, × 96.* The small, colorless polyhedral grains and the prisms with rounded ends are alit; the darker irregular patches of granular aggregate are belit, and the very dark interstitial matter is celit. The larger irregular light areas are vesicles.

alit is seen in grains and prisms, belit in an aggregate of round grains; the dark interstitial material is celit. Fig. 2 is a photomicrograph of the same section much more highly magnified (x725); alit is here seen in characteristic crystallization, with included gas bubbles; the dark interstitial matter is celit.

These constituents are seen to best advantage in thin sections cut from hard, well sintered nodules of Portland cement clinker; the photomicrographs shown in Figs. 1 and 2 are fairly representative of such sections. The components are sharply defined, easily differentiated, and do not encroach

*Magnification refers to diameter of printed illustration, as it appears on the page.

upon one another. In sections cut from friable, cindery and less perfectly sintered clinker, areas composed of a confused mixture of imperfectly developed alit and belit, mixed with celit, predominate. This transition material, representing incompletely developed alit and belit, is seen chiefly in friable

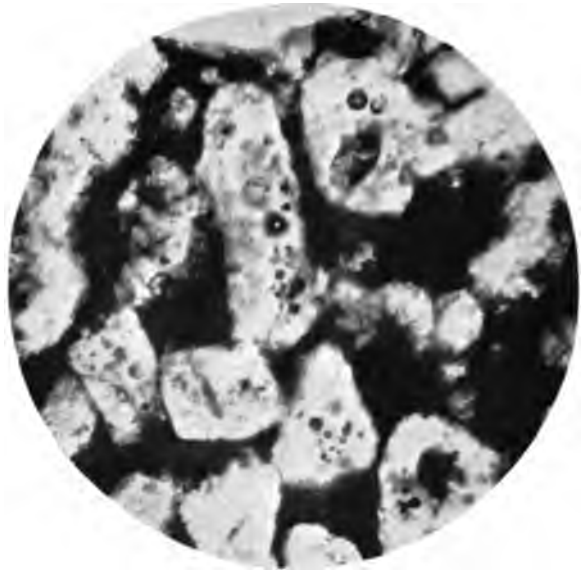

Fig. 2. Portland cement clinker; ordinary light, × 725. This illustrates the character and habit of the alit; note the numerous gas inclusions, judged to be carbon dioxide. The dark interstitial material is celit.

underburned clinker, which is largely composed of this indefinite mixture, the underdevelopment of which seems to be a result of underburning; hence the components of cement clinker may have formed during the heating of the raw materials and not as a result of crystallization from a previously formed solid solution.

Le Chatelier states, (loc. cit.) "The psuedo-cubic crystals (alit), primary elements, did not melt (i. e., were not formed by crystallization from a fused mass), but were formed by chemical precipitation among the brown fusible material (probably celit) which, after serving as a flux, thus rendering possible the chemical reactions, solidified on cooling and filled the empty intervals."

Considering the hard sintered nodules, and their vesicular habit (Fig. 1), it is certain that partial, or at least incipient fusion takes place to some extent in the kiln; and it is quite conceivable that the partially fused material might react with the unfused portion, producing the constituents mentioned. At any rate, it is evident that there are formed in the clinker certain components which have a mineral identity, capable of reacting with water when brought into contact with it, especially if they are previously finely ground, and possessing a definite cementing value.

The constitution of these components is not quite clear; by means of micro-chemical reactions on thin sections Le Chatelier (loc. cit.) concludes that the psuedo-cubic crystals (alit) are composed of silica and calcium oxide (tri-calcium silicate), and the "colored flux" (celit) filling the spaces left by these crystals is a double silicate of alumina, ferric oxide and calcium oxide. Of these, the first only (alit) is regarded as the essential element of cement.

Meade [4] quoting Richardson [2] defines alit as a solid solution of tri-calcium silicate in tri-calcium aluminate; and celit as a solid solution of di-calcium aluminate in di-calcium silicate. Desch [5] states that the essential hydraulic constituents of cement (alit) is a "solid solution of at least three components." The constitution of belit is much more problematical than that of alit, but the general opinion of those who have endeavored to ascertain its character is that belit is a calcium aluminum silicate, similar in composition to gehlenite, $Ca_3Al_2Si_2O_{10}$.[6] This, however, is not at all certain.

It seems probable that the constitution of the components is even more complex than postulated by the investigators mentioned; their work has, however, established the fact that the character of the cement made from clinker of this type is dependent upon the proportion between the constituents named, alit especially being the component of most importance.

Transformations which Occur During and Immediately Following the Setting of Cement.

When cement is gaged with the proper quantity of water, certain transformations take place which have been made the object of much study, the problem having been at-

tacked both in a chemical and microscopic way; from the mass of evidence presented two opposing theories have been advanced. Thus, Richardson (loc. cit.) concludes that the setting of cement is almost entirely due to alit, celit being practically unattacked; and that the strength of Portland cement after setting is due entirely to the crystallization of calcium hydrate under certain favorable conditions, and not at all to the hydration of certain silicates and aluminates.

Others favor a collodial theory, more particularly to account for the hardening which occurs subsequent to the setting of cement. Michaelis [7], for example, concludes that the small amount of water with which cement is gaged forms an excessively supersaturated solution of various salts which react with each other, producing compounds which are insoluble in concentrated lime water, and hence crystallize in needle shaped crystals; a point is soon reached, as this process continues, at which the over saturated solution suddenly coagulates, forming a hydrogel, in which the needle shaped crystals are embedded. In the beginning, the hydrogel is assumed to be soft because of much contained water, which, by the process of osmosis, is gradually extracted by the cement grains embedded and surrounded with it; this results in the gradual dessication of the gel, which also absorbs calcium hydrate, thereby hardening. Michaelis further definitely states (loc. cit.) that "the formation of a colloidal calcium hydro-aluminate and calcium hydro-ferrite is the only essential and important feature in the hardening process of all known calcareous hydraulic cements."

Desch [5], see also [9], has used the metallographic microscope in connection with the study of cement and concrete, and Johnson [8] describes, in a recent series of articles the results obtained through the use of the same instrument, which, howver, is limited in its application to the observation of features of a mechanical nature, such, for example, as cavities, vesicles, proportion of aggregate present, fractures, etc.; features which, provided they exist to an abnormal degree, may be a contributing cause of failure in a concrete structure, regardless of the nature of the cement used.

Considering the important part played by calcium hydrate, it was deemed advisable to determine the nature of the crystals formed when a solution of the compound in water evap-

orates spontaneously in an atmosphere free from carbon dioxide. Under such conditions, the resulting crystals exhibit a spherulitic habit, occuring both in individual spherulites (Fig. 3) and in an extremely fine aggregate composed of innumerable minute superposed spherulites (Fig. 4). This

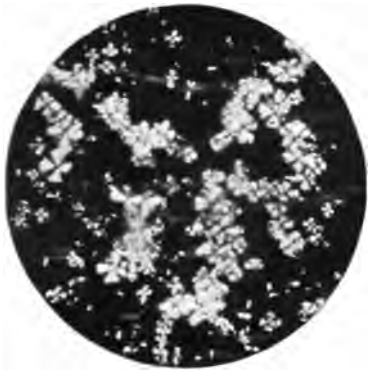

Fig. 3. Calcium hydrate spherulites; nicols crossed, × 430. These crystals were obtained by the spontaneous evaporation of a solution of calcium hydrate in an atmosphere free from carbon-dioxide. Compare Figs. 6 and 8.

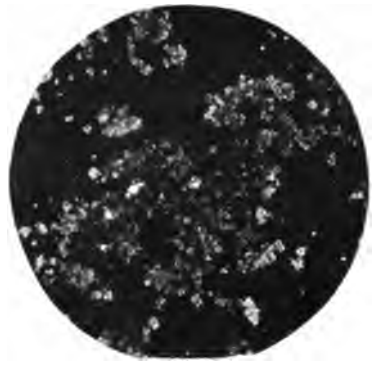

Fig. 4. Calcium hydrate in minute, confused aggregate; nicols crossed, × 430. This aggregate results from the superposition of innumerable minute spherulites; the superposition of spherulites with varying orientation causes varying birefringence in the mass, some places appearing optically isotropic. Free residual primary calcium hydroxide in cement, and in the cement of concrete, has a similar form and structure; compare Fig 5, BV1 and 14b.

spherulitic habit is well shown in polarized light, the characteristic black cross being plainly visible; the radial fibers composing the spherulites are negative in elongation and exhibit moderate birefringence. When, as in Fig. 4, a confused aggregate results because of superposition, the birefringence varies, being, in general, sensibly lower and optical isotropy also occurs in small scattered areas; such phenomena are to be expected when superposition occurs.

Cement, either neat or mixed with aggregate, shows a similar ground-mass habit 24 hr. after gaging. Thus, Fig. 5, B. V. 1 has a ground mass made up of crystalline calcium hydrate in minute confused aggregate, surrounding and in

intimate contact with a multitude of grains composed of particles in all stages of hydration, and unaltered fragments as well. The smaller grains are isotropic, and may be regarded as hydration products contemporaneous in formation with the calcium hydrate; the larger grains are clearly unattacked particles of residual clinker, the greater number of which remain unaffected even after a prolonged lapse of time. (Fig. 13). Johnson [8] regards most of these larger fragments as cement particles coalesced by the action of surface tension and bound together with needle-like crystals formed by incipient hydration, and thereby protected from further action.

The writer is not in accord with this interpretation, since a study of numerous thin sections of both cement and concrete proves these grains to be unattacked fragments of original clinker; they possess the structure and optical properties of the components seen in thin sections of the clinker (Fig. 1), and in many instances exhibit angularity of form.

Regardless of the nature of these particles, however, it is clear that they act as so much inert material, reducing the cementing efficiency of the ground clinker to a considerable extent; their presence also explains the fact, which has been observed by previous investigators [9],[10] that set cement, when reground and gaged with water a second time, will again set.

In addition to the fragments of residual clinker, isotropic hydrated grains and crystalline calcium hydrate, two other components were observed which will, for convenience, be called (a) "primary colloid," and (b) "amorphous constituent" proper. Of these, the latter is the component of chief interest and greatest importance.

The primary colloid was seen, in the thin sections studied, in small areas irregularly and somewhat sparingly distributed, intimately mixed with the calcium hydrate, the mixture possessing a minutely lamelloid structure, resembling a eutectic of exceeding fineness. It is interpreted as having formed by the co-precipitation from the excessively supersaturated solution, resulting when cement is mixed with water, of calcium hydrate and a small quantity of a collodial substance of uncertain composition, arising from the hydration probably of the alit. These eutectic-like areas of primary colloid are of limited extent and do not in the least resemble the dense,

structureless, semi-transparent component called the amorphous constituent proper, which is believed to be a secondary product of relatively later formation, although small patches irregularly distributed occur in some of the specimens even at the age of 24 hr.; this is probably due to the fact that the amorphous constituent proper begins to form soon, or immediately, after final set takes place, the rapidity with which it forms depending apparently upon the kind of cement.

Thin sections prepared from cements stored 24 hr. in the damp closet present, therefore, certain features which seem to indicate that the primary products of hydration are: (a) crystalline calcium hydrate of spherulitic habit, derived from the hydration of the alit, forming a ground mass; in which are embedded (b) isotropic grains, derived in greater part, probably, from the hydration of the celit, which are probably hydrous aluminates and silicates of no very definite composition; and (c) fragments of residual unattacked clinker. (d) Small areas of primary colloid mixed with calcium hydrate, and minutely lamelloid in structure.

In none of the specimens examined at this stage has the amorphous constituent proper been observed in extensive development.

After a lapse of 24 hr., under favorable conditions of storage, and generally within the space of five or six days, a further transformation occurs which seems to be a result of some sort of reaction between the primary colloid, the calcium hydrate groundmass, and the small isotropic hydrated grains embedded in and surrounded by it; there is developed a universal, dense, formless, structureless, semi-transparent* and probably amorphous substance which obscures everything in the field with the exception of the larger fragments, which are thought to be unattacked particles of residual clinker, previously mentioned (Fig. 5, B. V. 2).

It is difficult to explain the processes involved in the more or less gradual development of this amorphous constituent, and equally difficult to determine its constitution. The chief objection to the conclusions of previous investigators, based on results obtained by chemical methods, is that the condi-

*Using a 1/12-in. oil-immersion objective, and strong light, transparency results in many instances.

tions under which their experiments were conducted were not representative of conditions actually existing when cement or concrete is mixed with the proper quantity of water; thus, Michaelis (loc. cit.) agitated 1 gram of cement with from 2 to 4 liters of water, to which was added 1 c.c. of calcium hydrate

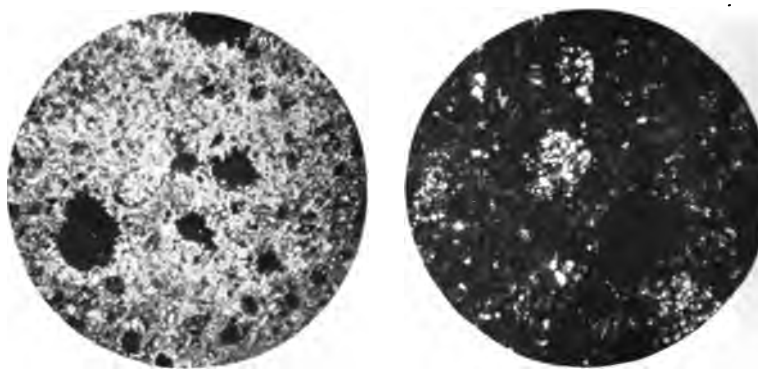

Fig. 5. Sample BV., neat cement, × 64, nicols crossed. B.V.1 was stored in the moist closet 24 hr.; B.V.2 was stored in moist closet 24 hr., then under water for 6 days. This illustrates the development of the "amorphous constituent." B.V.1 is composed of a multitude of grains of all sizes embedded in a groundmass of crystalline calcium hydrate; compare the groundmass structure with that shown in Fig. 4. All the small grains have been rendered optically isotropic by hydration, and they, as well as the calcium hydrate, are judged to be hydration products. During the 6-day interval these small isotropic grains, embedded in and surrounded by the calcium hydrate seem to have reacted with it, producing the "amorphous constituent" seen in B.V.2, in which no free calcium hydrate can be identified.

solution. Some of the results obtained by investigators using microscopic methods are likewise open to the same objection [11], [12]. If the conclusions of Michaelis previously referred to are correct, the formation of the complex colloid is essentially contemporaneous with the crystallization of the calcium hydrate; hence it should appear in complete development in specimens of set cement even though but 24 hr. have elapsed subsequent to the mixing of these cements with water. As before stated, the amorphous constituent in full development has not been observed, however, until after a lapse of several days; it thus seems to be of secondary origin, formed by a progressive but relatively rapid reaction betweeen the calcium hydrate and other primary hydration products, as explained.

It is, at any rate, clearly a component of the utmost im-

portance, and its presence or absence is a criterion by means of which the fitness of a cement or concrete may be judged, more especially with reference to the uses of the material in structures intended to be exposed to the action of water.

After this constituent has attained its complete development,

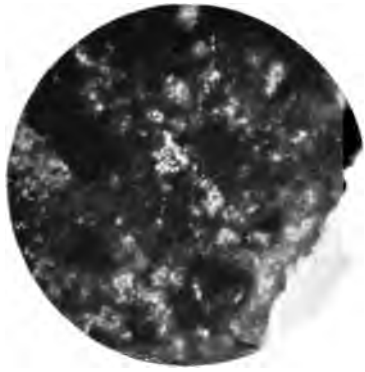

Fig. 6. B.V.3; nicols crossed, × 430. Sand cement briquette (1:3) stored 28 days in water. Note the spherulitic calcium hydrate; compare Figs. 3 and 8.

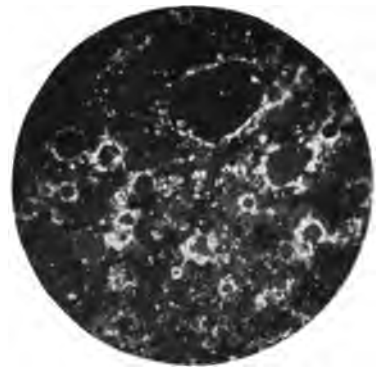

Fig. 7. P.W.6 × 64; nicols crossed. Neat cement, 24 hr. in damp closet, 6 days under water. The amorphous constituent is fully developed; spherulitic calcium hydrate lines the vesicles. When examined under much greater magnification well formed spherulites are seen similar to those shown in Fig. 8.

nowhere does identifiable calcium hydrate appear except in small isolated areas, where it is seen occasionally in spherulitic form (Fig. 6), and as a lining of vesicles (Fig. 7); in concretes it likewise appears in voids and cavities as a lining, and as a film surrounding fragments of the aggregate with which poor contact was made initially by the cement matrix; this feature serves as a criterion by which one may judge improper and insufficient mixing. It is in these latter situations that individual spherulites of calcium hydrate may be seen to best advantage (Fig. 8).

In the case of concrete certain conditions, which as yet have not been fully ascertained, may partially inhibit the formation of the amorphous constituent proper, leaving areas of greater or less extent composed of residual free calcium hydrate; a too rapid drying out of the concrete after mixing

seems to be one of these conditions, for, if cement is allowed to harden in air, either immediately after gaging, or after storage in the damp closet for 24 hr., the development of the amorphous constituent is arrested. This seems to indicate that moist conditions are essential to the proper and complete

Fig. 8. B.V.4 nicols crossed, × 1030. Sand cement briquette, stored 10 years in water. Spherulites of calcium hydrate, lining a void. Compare Figs. 3, 6 and 7.

development of this important component; another factor tending to produce the same result may be an improper proportion between the alit, belit and celit in the original clinker, which in turn might be a result of improper burning.

It may be observed that the presence of a considerable quantity of free, unchanged residual calcium hydrate in concrete structures, from whatever cause, is an element of weakness; due to its presence, possible future disintegration may be initiated, especially, and almost certainly, in those structures exposed to the joint action of air and water (Fig. 14b).

Further Transformations Subsequent to the Complete Development of the Amorphous Constituent.

When cement, either neat or mixed with aggregate, is stored under water for a considerable period, certain other substances are gradually formed within the rigid mass, by processes necessarily slow in operation, which depend upon the presence of water for their completion. These transformations result in the production of crystalline matter which must be derived from the amorphous constituent since most of the larger fragments of residual clinker remain unaffected even under these conditions; the fact that these transformations are effected is sufficient proof that recrystallization does occur, although the action generally is extremely slow, and, provided proper conditions be maintained, may be continued through a long interval of time.

It is unlikely, however, that complete recrystallization will ever be attained, because in actual structures the necessary conditions are lacking, and even where such conditions exist it is possible that equilibrium will be reached between the reacting components before such an event transpires. In the thin sections examined, the following substances have been identified as having resulted from transformations of this character: (a) Secondary crystalline calcium hydrate. (b) Crystalline calcium carbonate (calcite). (c) Zeolitic matter.

Secondary crystalline calcium hydrate occurs in clear hexagonal crystals, some of which give good uniaxial and negative interference figures, and in irregular areas probably representing places formerly occupied by grains of residual clinker, now entirely altered; because foreign matter, also crystalline, is generally included in these areas, in more or less symmetrical arrangement. Even the well shaped basal plates (Fig. 9) frequently contain so much foreign crystalline material, which seems to be a silicate of some kind, as to obscure the interference phenomena.

When briquettes of neat cement, stored for 5 or 10 years under water were broken, hexagonal plates of this material were observed in voids; these could be easily detached and subjected to further tests to prove their identity, as mentioned by Le Chatelier (loc. cit). The material is present, however, to a very limited extent, and while an interesting component,

it is not important; it has never been observed in any of the concrete specimens examined.

Frequently associated with, and included in, the crystalline secondary calcium hydrate are minute grains, patches of granular aggregate, and occasionally minute rhombic crys-

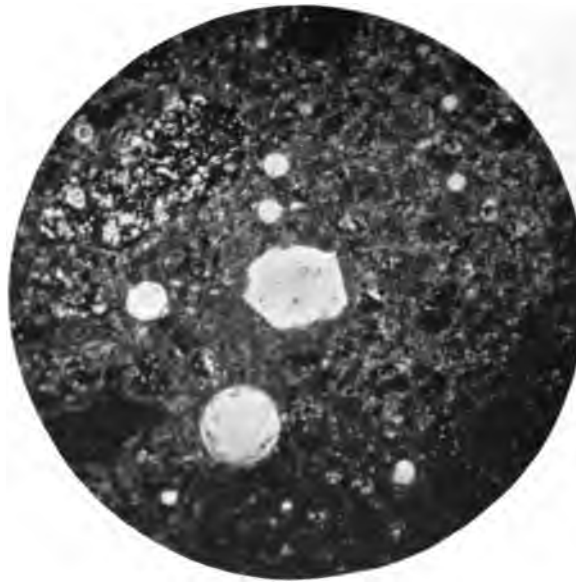

Fig. 9. B.V.2; ordinary light, × 103. Neat cement briquette, stored one year in water. The round clear areas are vesicles, which are generally lined with calcium hydrate, with which zeolitic matter is sometimes associated; the large hexagonal plate in the center is secondary calcium hydroxide. This plate is normal to the optic oxis; with crossed nicols it is observed that a silicate of some type has been included in it, which appears in the dendritic form. Note the grains of residual clinker.

tal, of calcite; this substance also occurs in very small quantity scattered through the groundmass; not infrequently very perfect interference figures are obtained from some of these minute patches. The total quantity present in test pieces stored under water is always very small.

The third substance, which has optical properties similar to the zeolites, and, because of the close resemblance it bears to the minerals of the zeolite group, will be designated zeolitic matter, is much more abundant. It has been observed in (a) minute individual crystals in the groundmass (Fig. 10); (b)

filling, and partially filling voids and cavities (Fig. 11); (c) distributed through the groundmass in irregular patches of small area; and (d) in a thread-like network of crystalline matter; as well, (e) as a crystalline rim surrounding a core of amorphous substance, in which situations it has clearly

Fig. 10. B.V.2; nicols crossed, × 400. Neat cement briquette stored in water. This illustrates the character and habit of the secondary minerals judged to be zeolites; although they occasionally appear as isolated crystals, they more frequently are seen filling vesicles in interlocking needles, as shown in Fig. 11.

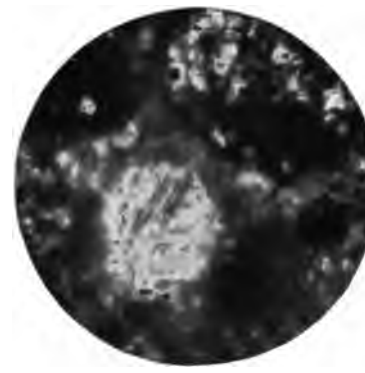

Fig. 11. B.V.3, nicols crossed, × 430. Neat cement briquette, stored 10 years under water, showing a vesicle, filled with secondary material in interlocking needles, judged to be zeolites. Compare Fig. 10.

resulted from the later alteration of fragments of residual clinker (Figs. 12 and 13); also (f) associated with calcium hydrate, in voids.

Where this zeolitic matter occurs in invidual crystals, and in groups of interlacing needles filling voids, there appears to be two varieties; this is thought to be due to variously oriented crystals of the same kind, which exhibit stronger or weaker birefringence, depending upon the orientation of the individuals, since in those areas showing this feature application of the Becke test failed to reveal any difference whatever in the refringence.. All of the acicular crystals, moreover, regardless of their berefringence, have positive elongation and parallel extinction; in numerous places small areas of what was judged to be the same material gave fairly good interference figures, optically negative and apparently uniaxial. The

material is probably biaxial, however, with a very small optic angle; in this, as in other characteristics, it resembles certain of the zeolites, and it seems not unreasonable to conclude that this substance is probably a hydrous sodium calcium aluminum

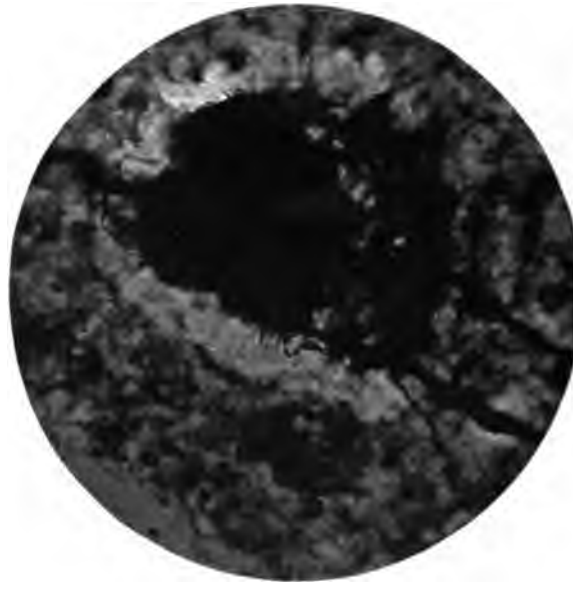

Fig. 12. B.V.1, × 700; ordinary light. Neat cement briquette, stored 28 days under water, showing a residual clinker grain completely altered by secondary processes. The alteration of this grain has resulted in an increase of volume, which has exerted local disruptive stress sufficient to cause fracture; the grain is rimmed with crystalline material surrounding a core of a translucent amorphous substance which also acts as fracture filling; the fractures extend to other and similar grains, and to vesicles.

silicate belonging to that group, but which can not be definitely referred to any one of them thus far described.

The later alteration of fragments of residual clinker embedded in the rigid mass resulted occasionally in the production of a rim of zeolitic matter, surrounding a core of translucent amorphous substance; the increase in volume due to such action frequently causes local disruptive stresses which produce fractures radiating from these grains, and generally connecting with voids and with other grains similarly affected, the fractures being filled in some instances with the amorphous substance (Figs. 12 and 13).

It would thus appear that the hardening of cement, subsequent to setting, and its increase in strength with age, are due not alone to the desiccation of the hydrogel and absorption of calcium hydrate by it, as postulated by Michaelis (loc. cit.) but to the partial recrystallization of the amorphous constituent as well.

Fig. 13. B.V.3, ordinary light, × 140. Neat cement briquettes, stored 10 years in water; the larger particles of residual clinker are still unaltered; the very small grains have disappeared, and the "amorphous constituent" has changed in character. Under higher magnification a network of crystalline material is visible, indicating that recrystallization processes have been in operation. Note the altered grain of residual clinker connected by fracture lines with the large vesicle. Most of the vesicles are filled with zeolites similar to those seen in Figs. 10 and 11.

Application of these Observations to the Study of Concrete

With the aid of the observations enumerated, textures, structures, and other features seen in thin sections of concrete may be interpreted with greater exactitude; not only, however, should the character of the cement matrix itself be determined, but also the nature, condition and proportion of the aggregate, and voids, fractures, introduced substances, extent of carbonation, and the character of the contact be-

tween the cement matrix and the aggregate as well. For these determine the integrity of a structure, serving as criteria by means of which the fitness of the material may be judged.

Thus, with reference to the problem in hand, it was observed that in the specimens taken from the structure where

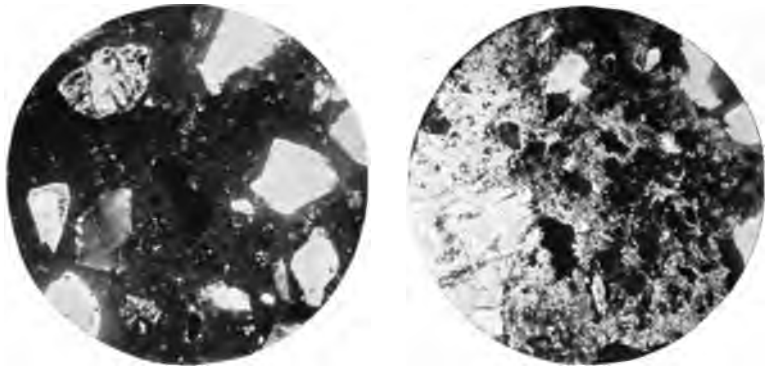

Fig. 14. Good and Defective Concretes. Nicols crossed, × 75. Fig. 14a is first-class concrete in good condition; the amorphous constituent is fully developed, the texture fine and even, and contact with aggregate good. Residual fragments of belit character are seen in the groundmass. Specimen taken from an actual structure. Fig. 14b is a specimen of the defective concrete in question. Texture variable, mottled structure; small patches of the amorphous constituent are seen in irregular distribution in a groundmass consisting of calcium hydrate; in other thin sections, not shown here, there are seen a net work of crevices, along which carbonation and solution are progressing, poor contact, too many voids and cavities, and other features, all of which collectively are contributary causes of failure.

disintegration was in evidence, the amorphous constituent was present to a very small extent, its development having been inhibited by some condition not determinable; the small patches of this component existing in the concrete were irregularly distributed through large areas of residual, free, crystalline calcium hydrate, thus giving the cement matrix an extremely variable texture, and a "mottled" appearance (Fig. 14b; compare with 14a). Furthermore, a noticeable lack of residual clinker fragments was apparent; this feature may possibly indicate an underburned cement, or at least a cement made from a clinker in which friable, soft cinder predominated, the components of which were imperfectly developed, and from which might be liberated an undue amount of calcium

hydrate when the resulting cement is gaged with water; this explanation is tentative, however.

There was also observed, in thin sections of the defective concrete, a system of hair-like crevices, ramifying throughout the mass, connecting cavities and voids, and serving as channels for the transfer of solutions, along which carbonation and the dissolving of the calcium hydrate were progressively taking place.

The aggregate was not proportioned according to specifictions, the mixture being too rich; the aggregate fragments, moreover, made poor contact with the cement matrix, as a result of insufficient mixing, and indicated by a film of calcium hydrate, in some instances, and limonite (with which the aggregate used was coated) in others. The aggregate itself, which was glacial gravel, contained a large proportion of schist-pebbles, many of which were considerably altered; it was of sufficiently good grade for massive construction work, however, with proper washing.

These features, together with others not enumerated, served to demonstrate that the relatively rapid disintegration which was taking place at, and a little above, the water line, was due to a number of contributing causes, not the least of which was the presence of an abnormal quantity of free calcium hydrate in the cement matrix of the concrete, which was being progressively carbonated and dissolved; the excessive amount of this substance being in turn due to the suppression of the development of the amorphous constituent, the cause of such suppression not being determinable, though probably due, in this case, to an initially poor cement, with too great a proportioning of the alit constituent.

Conclusions

It would therefore appear that certain features may serve as criteria, with the aid of which the fitness of cement and concrete may be judged, and where actual failure has occurred, the cause or causes may be ascertained. Such of these as have proved useful are here appended, as a basis for further work along these lines:

1. Presence of the amorphous constituent in complete development; it may exhibit incipient or partial recrystallization.

2. A minimum quantity of free residual crystalline calcium hydrate; when present, it should be confined to small isolated patches in the groundmass, and to voids and cavities, as a lining.

3. The texture of the cement matrix should be exceedingly fine and very even. A variable texture and mottled structure indicate an abnormal quantity of calcium hydrate.

4. The occurrence, in the cement matrix, of fragments of residual clinker of belit composition in conjunction with fully developed amorphous constituent, seems to be indicative of properly burned cement.

5. Carbonation should not exist to any great extent.

6. Cracks, crevices, fractures, voids and cavities should exist to a minimum degree; it should be especially noted whether a netlike system of crevices has developed, connecting cavities and voids, and if so, whether carbonation and solution are progressively in operation along such channels.

7. Secondary introduced material deposited by crystallization from infiltrating solutions, either by actual conveyance of material from without, or by a reaction between substances in solution and the walls of the crevice, should not be in evidence.

8. Good firm contact between the cement matrix and the aggregate should be shown. Poor contact, which is a result of insufficient mixing, is indicated by films of calcium hydrate, or hydrated ferric oxide, with which much of the gravel, especially of glacial origin, is coated, surrounding pebbles and fragments of the aggregate.

9. The aggregate should be properly proportioned, and in order to be of the first grade the coarse part of it should consist of firm, unaltered angular fragments of preferably igneous rock, in which no secondary structures have been induced; where gravel of glacial origin has been used, note especially the schistose pebbles, as these are liable to be considerably altered.

No doubt some of the opinions here set forth will need modification as further work proceeds; the writer ventures to predict, however, that applied petrography will solve many of the problems connected with concrete, and that it may even be possible to determine beforehand whether a certain grade

of cement will prove desirable for particular kinds of structures or not, depending upon the conditions to which they may be exposed.

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SMELTING METHODS AT MAGISTRAL, DURANGO, MEX.

BY ROBERT W. BISSELL.*

The Magistral group of mines, owned and operated by the Lustre Mining Co. is situated near Santa Maria del Oro, Durango, Mex., about 50 miles south of Rosario, the present terminus of the Parral branch of the National Lines of Mexico, formerly the Mexican Central Railroad.

The gold mines in this group have been worked at various times since 1708, and possibly even prior to that date; but the records are meagre, and except for the enormous stopes little remains to indicate the wealth obtained from this district.

Following the expulsion of the Spaniards in the first decade of the nineteenth century, there was a period of comparative quiet, succeeded by a period of mining activity conducted by a Scotch company in the early forties. Most of the white men were murdered—supposedly by Indians, probably by bandits—and the Scotch withdrew about 1856. Local interests continued working in a small way until the present company came into the district about 1887. At that time about 500 arrastras were in operation but the crude methods and limited output did not yield much profit. The more accessible free-milling oxidized ores were nearing exhaustion. The sulphide ores, when water did not prevent their extraction, were broken fine, spread on the patios in the sun to weather, and the process of oxidization was aided by frequent wetting. The richer sulphides were roasted in heaps. The resultant material was finally ground fine and amalgamated in arrastras, the pulp subsequently washed in masonry tanks, the amalgam recovered, and retorted.

The property owned by the Lustre company comprised some 200 pertenencias and extended northwest and southeast about three miles. The Cocinera mine near the centre of the property is at the old mining town of Magistral, a name derived from the sulphate of copper formerly extracted in considerable quantity from veins on the property, and transported 100 miles across the mountains on burros for use in the patio process at Mapimi. It is at this mine, the Cocinera, that the greatest amount of development work has been done.

It is the largest producer and here are located the reduction and power plants and the buildings of the company.

On first taking hold of the property in 1887, Jiminez, a town on the main line of the Mexican Central Railroad, was the nearest railroad point, something over 100 miles to the southeast, over a rough and little used wagon road. Because of the expense of transportation it was not until 1891 that the company had completed its first plant, a 40-stamp mill built by the Mecklinburg Iron Works.

The very high extraction obtained in the arrastras, and the fairly satisfactory results obtained in two Griffin mills with which the company had done its preliminary work, led them to believe a satisfactory saving could be accomplished by plate amalgamation alone, but as the percentage of sulphide ores continuously increased it was found necessary to install a concentrating plant to treat the tailings. Classifiers, followed by Wilfleys and vanners accomplished the desired results, but the disposal of the concentrates became an increasingly serious question as the percentage of sulphide ores continued to increase. This condition finally resulted in the construction of a chlorination plant, with Brückner roasters, designed by Adolph Theis and erected by Ernest A. Theis, under whose skilled management very satisfactory results were obtained.

A year or two later, mine development had proceeded to a point where the mill was utterly unable to treat the available tonnage, and a larger reduction plant became a necessity. About this time Victor G. Hills, consulting engineer of the Portland Gold Mining Co. of Colorado Springs, reported the ore to consist of four well-marked classes:

1. Quartz-pyrite, consisting of 70% quartz and 30% pyrite.
2. Basic ore, consisting of 75% pyrite and 25% quartz.
3. Red ore, consisting of 40% quartz, 25% iron oxides, 20% calcite and 10% alumina.
4. Spar ore, consisting of 35% quartz, 10% pyrite and 55% calcite.

A general analysis of the developed ore gave: SiO_2, 42%; Al_2O_3, 5%; $CaCO_3$, 25%; $MgCO_3$, 2%; FeS_2, 22%; FeO,Fe_2O_3, 3%; Cu, 0.9%; Mn, 0.20%; Au, 0.56 oz.; Ag, 0.25 oz. per ton.

The ore exposed on one side only in lower levels, and therefore not included in the above analysis, was largely basic and

Mr. Hills reported that he considered the conditions ideal for pyritic smelting, because of: 1. Average of 0.9% Cu (as a collector). 2. Iron sulphide in superabundance. 3. No lead, zinc or bismuth. 4. Lime ores (hence no barren lime flux needed). 5. Sufficient quartz.

Acting on this suggestion the new manager began a series of tests to determine the comparative cost of concentrating his ore by furnace methods, so as to admit of shipping matte to the nearest smelter. A small 36-in. round water-jacket furnace was first tried, followed by one of 42-in. diameter. The results were promising, and two 48-in. steel water-jackets were erected and put into regular operation, concentrating 15 to 17 tons of ore into one ton of matte. Later a 42 by 120-in. furnace was added.

In 1899 the railroad had been extended to Rosario, within 50 miles of the property. Late in 1906 the company received definite assurance that the branch line from Jiminez to Parral and Rosario would be extended to Magistral, and it therefore began the construction of the present smelter, which consists of three 40 by 168-in. steel water-jacket blast furnaces. The plant was only partially completed when the panic of 1907 stopped all railroad construction and effectually prevented the company from completing its plant. It was, however, necessary to blow in one of the furnaces, and in exceptional circumstances, when the coke supply permitted, two were operated for short intervals until the retirement of President Diaz threw the country into a state of anarchy and necessitated a complete shut down.

The Smelter.

A hillside site was chosen for the present smelting plant. Ore from the various mines is received in cars at the highest point. The loaded cars pass over a scale, are weighed, pass directly forward, and are dumped over a grizzly set at 3.5 in.; the oversize is fed directly to a No. 7½ McCully gyratory breaker, driven by a slow-speed 25-h.p., G.E. induction motor. The crusher is capable of handling pieces 40x15x15 in, though pieces of one-third this size are the largest allowed to leave the mine stopes. After passing the crusher the ore is drawn from the receiving bin into 2-ton cars, run by hand over elevated tracks, and dumped into the ore bins, where the several

classes are bedded. The end bins are reserved to receive excess of basic or spar ores as the case may be, and thus is secured a ready means of varying the charge as occasion requires.

From the ore beds the charge is shoveled into two-wheeled steel charging buggies, run by hand over the charging scales to the charge floor, and dumped directly into the furnace. Coke from the coke storage, at the left of the ore bins, is received and handled in the same way, but is generally dumped on the charging plates immediately in front of the furnace, and fed by hand.

The three blast furnaces were built by the El Paso Foundry and Machine Co., and are each 40 by 168 in. at the tuyeres. The jackets are 10 ft. long and 42 in. wide, with a 4.5-in. water space. Each of the eight side jackets is pierced for four 4.5-in. tuyeres, fitted with a boiler-tube thimble and stayed with four stay bolts. Cast-iron thimbles ½-in. thick are fitted loosely into the tuyere openings to protect them from injury. The tuyere line is 3 ft. from the bottom and 7 ft. from the top of the jacket. The jackets are set at a batter of 1:12 so that the total bosh is 2 in. per foot. The end jackets are vertical. Above the jackets is a mantle 2 ft. deep and sloping back to the charge floor at an angle of 45°. The purpose of these long feed plates, over which the charge is dumped, is to arrest the finer material and cause it to fall along the sides of the furnace, while the coarser material naturally feeds towards the center.

The tuyeres are of cast iron, fitted with a 3-in. fusible plug to permit ready relief in case, as sometimes happens, the spout should become blocked, causing a temporary accumulation of matte and slag to rise above the tuyere line in the furnace. Each tuyere is also fitted with a quick-opening crane gate-valve to regulate the blast. Tuyere caps, each fitted with a peep hole, are quickly removed by a quarter turn. The tuyere pipes are of 5-in. boiler tube and enter the 20-in. sheet steel bustle pipe through a cast-iron stuffing box, thus insuring abundant play for expansion and ease of adjustment.

Cooling water enters the jackets through a 3-in. water pipe above the tuyeres, where it impinges against a diffusion plate riveted to the 5/16-in. back sheet of flange steel. The fire sheets are of ⅜-in. fire-box steel. The cooling water is dis-

charged through a 2-in. goose neck fitted to a steel pocket at the top of the jacket. The discharge from each jacket is regulated by a valve and all meet at a point at the rear of the furnace, where they are always visible from both the charge and the tap floors. The discharge is into a sump feeding two 5-in. Gould centrifugal pumps, each direct connected to 15-h.p., G. E. induction motors. The pumps lift the water 25 ft. above the charge floor, from which point it flows through an open launder to a cooling tower, and thence to the reservoir, from which it again flows to the jackets, under an 18-ft. head. The duplicate pumps are run alternately and each is capable of handling the water needed for the entire plant.

The cooling water enters the jackets at atmospheric temperature and is discharged at from 80° to 90°C. The total consumption of water, including that used for wetting down, leaks, loss and evaporation, is about 1000 cu ft. per 24 hr. for each furnace. This loss is added to the system once each day and a record is kept. All water connections about the furnace are purposely made large to avoid the necessity of frequent cleaning due to precipitation of dissolved salts carried by the mine water used.

The blower plant consists of two No. 8½ Root, and one No. 7½ Connersville positive pressure blowers, each driven by a 125-h.p., slow-speed, G. E. induction motor. Each large blower furnishes 12,500 cu. ft. free air per min., the smaller, 8,000 cu. ft. per min. The blowers discharge into a 42-in. sheet steel main blast pipe, to which each furnace is connected through a McDonald blast heater. The heaters in turn are connected to the furnace bustle pipes. At the blowers the pressure varies from 16 to 24 oz. and at the furnace tuyeres from 11 to 17 oz., depending on furnace conditions. The drop in pressure is due principally to friction in the heaters, of which there is one for each furnace. These consist of 12 rows of 10-in. steel boiler flues 15 ft. long, 10 tubes in each row, connected at top and bottom by cast-iron manifolds. These are inclosed in brick chambers about 20 by 38 by 25 ft. inside measurements. They are heated by the waste heat from the furnace stacks, the gases being passed back and forth among the tubes by means of baffles. The velocity is reduced, the flue dust is settled to the bottom, and the gases pass on to a

header flue which connects to a main flue 7 ft. wide and 8 ft. 2 in. high to the spring line of a semicircular covering arch. This flue, 1100 ft. long, leads up the side of the mountain to a 40-ft. stack, giving a total height from the charge floor of 176 ft. Such dust as is not caught in the dust chambers is collected in this flue, from which it is removed about once a year.

The degree of superheat due to the McDonald stoves is from 100° to 110° F., and has been found to be a very distinct advantage in maintaining easy running of the furnaces. This is especially noticeable when the charge becomes more than usually silicious.

Formerly, brick for furnace bottoms and settler linings were imported from the United States, but later, with the exception of a few chrome brick used about the spouts, all were made on the premises from local clay. During the time that the first 48-in. round furnaces were in operation, a great deal of trouble was experienced due to the failure of the brick linings of the forehearths, and it was for this reason that in the new plant each furnace was provided with two forehearths, one on each side of the furnace. The quality of the brick was improved, however, and the ability to make a quick change of settler did not prove to be of so great importance in the new plant as was anticipated. When, however, a settler did go wrong it was only necessary to plug the spout, open the opposite side, and go ahead with the reserve forehearth.

Elliptical cast-iron slag pots of 16½ cu. ft. capacity, fitted with the worm and screw dump, mounted on four-wheel steel trucks of 36-in. gauge are used. Two-wheeled 1⅜ cu. ft. cast-iron matte bowls used at first were later replaced by steel matte pots of the same design. The original intention was to use Kilker matte cars and these will undoubtedly be installed when the railroad is extended to Magistral, and operations are resumed.

Furnace Operation.

As previously stated, the purpose in view was to accomplish a better and cheaper concentration than had been possible by the earlier methods. It was thought that with the advent of rail connections this could be accomplished by a partial pyrite, or raw-ore, smelting method, the product being

a 15 to 18% copper matte containing practically all of the gold and silver.

Typical analysis of the several classes of ore now produced are:

	SiO_2	Fe	MgO	Al_2O_3	S	CaO	Cu	Au
	%	%	%	%	%	%	%	$
Oxidized ore.....	62	13	3	4	2	2	0.5	12.00
Silicious sulphide...	42	26	2	7	19	3	0.9	13.00
Basic sulphide.....	18	40	2	3	35	2	1.1	8.00
Lime-spar ores....	9	5	2	3	2	48	0.2	3.00

By close supervision in mining and bedding, a quite uniform smelting charge is maintained. Low-grade matte, barrings, top-floor scoria, foul slag, etc., form a part of each charge, but is not regularly bedded with the ore.

The coke charge varies and has been, for short periods, as low as 5% but has averaged nearer 12%, based on the coke actually paid for at the ovens. This includes loss due to abrasion in handling and transportation.

The accompanying is a copy of an old charge sheet and is typical average practice. Shipping matte averaged about 15 to 17% copper, $155 gold and $4 silver per ton. It was all (about 8,000 tons up to the time referred to) sent to the American Smelting and Refining Co. at Aguascalientes, and was paid for at the following rates:

Gold, if at least 3.43 grams; pay for all at 62.8c. (U. S.) per gram.

Silver, if at least 50 grams; pay for 88.5% at N. Y. quotations.

Copper, if at least 5% dry assay; pay for 90% dry assay, less 6.61c. (U. S.) per unit, N. Y. quotations (E. & M. J.) for the corresponding week. A unit was 10 kg. Dry assay was wet assay less 1.3 units.

Slag losses, calculated back to original ore, amount to 74.6c. gold and 2.14 lb. copper per ton of ore. The flue-dust losses amount to 67.5c. gold and 1.19 lb. copper per ton charged. It is expected to recover a part of the flue-dust losses when the accumulation justifies a plant for its treatment.

An examination of the charge sheet shows a total recovery of 89% of the gold and 84.7% of the copper.

Charge Sheet, Lustre Mining Co., Magistral, Durango, Mexico, 1914.

	Tons Weight	SiO_2		Fe		CaO-MgO		Al_2O_3		S		Cu		Ore Value	
		%	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%	lb	Per Ton	Total
Oxidized	113	62	70.0	13	14.7	5	5.7	4	4.5	2	2.3	0.5	1,130	$12	$1,356
Siliceous sulp...	697	42	292.8	26	181.2	5	34.9	7	48.8	19	132.4	0.9	12,546	13	9,061
Sulphide	109	18	19.6	40	43.6	4	4.4	3	3.3	35	38.2	1.1	2,398	8	872
Lime-spar	81	9	7.3	5	4.0	50	40.5	3	2.4	2	1.6	0.2	324	3	243
Total raw charge.	1,000	..	389.7	..	243.5	...	85.6	..	59.0	..	174.5	...	16,398	...	11,532
Conc't matte....	30	..	.....	59	17.7	..	....	..	....	32	9.6	9.0	5,400	48	1,440
Coke	115	6	6.9	2	2.3	..	....	2	2.3	..	.....	...	.....	...	.....
Total charge....	1,145	..	396.6	..	263.5	..	85.6	..	61.3	..	184.1	...	21,798	...	12,972
Slag	825.4	..	386.6	..	221.2	..	82.3	..	53.2	..	17.0	...	2,143	...	746
Matte	62	..	.....	..	35.3	..	....	..	....	..	17.3	...	18,465	...	11,551
Flue-dust	30	..	10.0	..	7.0	..	2.4	..	8.1	..	1.8	...	1,190	...	675

Slag Composition

SiO_2	46.9 %
FeO	34.4
CaO-MgO	10.1
Al_2O_3	6.4
S	2.1
Cu.	0.13
Gold per ton.....	$0.88

Matte Composition

Fe	57.1%
Cu	15.0
S	27.9
Gold per ton.....	$186.30

Sulphur volatization, 148 tons, equal 85%.

Weight of slag, 71% of total charge.

Matte fall 5.4%.

Concentration, 16 of ore into 1 of 15% matte.

SPECIFICATION AND SELECTION OF ASPHALTIC MATERIALS FOR STREET PAVEMENT

BY FREDERICK O. X. M'LAUGHLIN.*

Since the time of Macadam, Telford, and Tresaguet, when road building was first founded on sound scientific principles, no event in the history of highway construction has had more far reaching effects than the introduction, in 1876, of natural bituminous concrete or asphalt as a surfacing material. When one remembers that not a single standard pavement in use to-day was in existence in America 40 years ago, it is easy to appreciate the rapid progress that has been made in the construction of roads and pavements. This remarkable advance has been made possible largely through the use of bituminous materials.

Bitumen, in one form or another, is used not only in the construction of sheet asphalt surfaces, bituminous concrete, and bituminous macadam roads, but also in asphalt block, as filler for other types of block pavements, for expansion joints, and as a dust layer on ordinary macadam roads. One might be justified in saying, therefore, that bitumen is the *sine qua non* of modern road and pavement construction. It would be impossible in a paper of this length to touch upon the use of bituminous materials in all the types of roads and pavements mentioned above. The scope of these remarks will therefore be limited to one type, namely, the sheet asphalt pavement.

Much has been written about the desirable characteristics of asphaltic materials for sheet asphalt pavements, about the advantage of this over other types of street surfacing, about the various causes of failure, and about the fundamental principles of construction. Many articles in the technical press on the subject of sheet asphalt surfaces are mere repetitions of information already in possession of the majority of engineers, information which, in many cases, is more fully and more ably set forth in modern textbooks on the subject. In this paper, therefore, it will be assumed that the reader is already familiar with the method of constructing the mod-

*C. E., Columbia, 1910.

ern asphalt pavement, with the essential characteristics of a good pavement, with the necessity for a firm and unyielding foundation, with the importance of proper grading and selection of the mineral aggregate, and with the general chemistry of the bitumens. The writer hopes to present new phases of the subject as follows: (1) by noting the conditions which gave rise to the long-term guaranty clause in specifications, and the reasons for its gradual abandonment; (2) by analyzing the question that arises with the elimination of this guaranty clause, i. e., restricted competition versus the use of untried materials; (3) by suggesting a possible solution of this problem.

When Trinidad Lake asphalt was first introduced as a paving material, engineers were skeptical as to its merits. It was a new and strange material, the properties of which were unknown to most engineers, and but little understood even by those responsible for its introduction. Not only did engineers know little of its road making qualities, but they knew less about the proper methods to be employed in laying such a bituminous surface. And, what is more important, this asphalt was a hitherto untried material; there were no records of service tests to indicate whether it would last one year, 10, or 20 years, under given conditions. It was a very natural procedure, therefore, for the engineer to place the whole burden of responsibility in case of failure on the promoter of this new material. The reputation of the engineer was thus safeguarded; the municipality was apparently relieved from financial loss in case of failure, and the promoters had the opportunity to demonstrate the excellence of their material at their own financial risk. In the abstract, this seems to have been the most equitable arrangement; and for the first years of the industry it was, no doubt, the only possible arrangement.

A review of the history of sheet asphalt pavements in the United States will show, however, that this attempt to shift the entire responsibility on the contractor, by means of the long-term guaranty clause, did not accomplish its purpose. This clause has proved unsound economically, of doubtful legality, at times unjust to the contractor, expensive to the city, the cause of much legal controversy, and, in many cases, impossible to enforce.

To this day, and throughout the whole period of its employment, the legality of the long-term guaranty clause has been attacked, and has been instrumental in defeating or invalidating many assessments. Where failures have occurred, the loss has usually been borne ultimately by the municipality, the enforcement of the clause, for many diverse reasons which need not be enumerated here, being impossible.

This long-term guaranty clause also materially increased the cost of pavement. In making his estimates a contractor was either inexperienced or never expected to abide by his contract if he did not safeguard himself against the expense of maintaining for 10 or 20 years a pavement the useful life of which he himself could not foretell. To cite a particular instance in New York City, due to the necessity for numerous street openings, the contractor made more profit on repairs and maintenance than on the original contract, the city paying for materials used, under agreement made years before, a price far in excess of the cost of materials at the time of resurfacing.

On the other hand, this clause frequently worked undeserved hardship on the contractor. He was generally required to follow strictly the methods of construction laid down by the engineer; and it was seldom appreciated that failure might be caused by faulty design, improper grading and poor quality of the mineral aggregate, unexpectedly heavy traffic, frequent openings, bad sub-surface drainage, as well as by failure of the bituminous binder.

As time went on, the necessity for the guaranty clause decreased. Engineers became more and more familiar with the properties of Trinidad asphalt, and with the best methods of handling and laying it. The engineers and chemists of the producing company, which introduced this natural asphalt, perhaps did more to bring about this increased knowledge than any independent engineer or chemist. Due to the enormous increase in the use of asphalt, engineers gave more thought and study to the formulation of scientific principles for constructing sheet asphalt surfaces, and thus gained confidence in their ability to design and construct a surface which would be creditable to them. Standard tests have been devised for determining the physical and chemical character of

asphalt, and sound scientific principles of construction have been evolved, have been tried, and have proved successful.

Trinidad Lake asphalt, through a long period of years, has proved to be a most desirable material for sheet asphalt surfaces, when they are constructed according to the present accepted methods. It has stood the test of actual use for a number of years, and an engineer now has available service records to show what may be expected of this material. Another important feature is that, from the time the first shipment was examined, to the present day, every cargo has shown the same analysis. The product is absolutely uniform, and methods of refining are constantly being improved, so that today there is no uncertainty about the characteristics or the results to be expected of natural Trinidad asphalt.

If, therefore, asphalt is no longer an untried material; if the engineer knows the best methods of construction, and has means of analyzing and testing this material within very close limits; if by actual results, asphalt has proved desirable paving material, of constant and uniform quality; it would seem that the long-term guaranty clause in specifications is no longer necessary. The conditions which made advisable the use of this clause are entirely changed, and since it must be admitted that such a clause has produced more harm than good, it would seem advisable and desirable to eliminate it from specifications.

Unfortunately, other conditions have arisen which prevent its absolute abandonment. Where in 1876, and for 30 years thereafter, the term "asphalt" was taken to apply to "Trinidad Lake asphalt", the natural product from Trinidad Lake being the only one on the market, today we find an endless variety of new, tried and untried, manufactured and natural, good, bad and indifferent, products on the market—all "bituminous materials" or "asphalt" according to definition, but differing most widely from one another.

The products now offered for use in sheet asphalt mixtures may be broadly classified into three groups:

A—Natural asphalt, such as Trinidad and Bermudez, the process of refining which consists merely in the removal of water, the lighter oils, and gross impurities, twigs, etc.

B—Combinations of certain hard natural asphalts, contain-

ing less than 60% bitumen soluble in 86°B naphtha, with asphaltic oils or residues incorporated by agitation or by the blowing process.

C—The "oil asphalts", so called because they are solid residues produced by distillation or oxidation of petroleums. Prevost Hubbard, speaking of road materials coming under the classification of bitumens, says,

"These products consist of a great variety of complex mixtures, solutions and emulsions of hydrocarbons and their derivatives, together with varying quantities of organic matter not bitumen, mineral matter, etc. They consist of petroleum and petroleum products, including residual petroleums, fluxes, oil asphalts, and fluxed or cut back oil asphalts, malthas, native asphalts, and other solid native bitumens and asphaltic cements produced by fluxing them; coal tars, and water gas tars, their distillates and residues, mixtures of tar with petroleum or asphalt products, bituminous emulsions and factitious asphalts, bituminous aggregates, including rock asphalts, or bituminous rocks, bituminous concrete or other bituminous topping.

"At the present time (1911) many highway engineers know bitumens only as black, more or less sticky substances which range from fluid to semi-solid consistency. To some they are all tars, or all oils, or asphalts, the meaning of these terms being at best very vague. Trade products are known by name, only, and when it is desired to describe these products in somewhat more detail, the use of such terms as 'asphaltic contents', 'percentage asphalt', etc., are often used with rare indiscrimination.

"It is often an exceedingly difficult matter for even the analytical chemist to differentiate between certain of these products, but the principal classes can usually be identified with little difficulty."

The introduction of these new, often poorly prepared or insufficiently tested, asphalts and asphalt mixtures was occasioned by the development of the asphaltic oil industry and the advent of the open specification, giving full and free competition to all materials, in an attempt to reduce prices. As might be expected, prices were lowered, but inferior, often worthless, materials were offered, accepted, and used, with disastrous results. The situation then was somewhat similar to that which existed in France about 1880, described as follows by E. Kuichling:

"It may also be mentioned that rock asphalt for street paving purposes was first introduced in Paris in 1854. Its use in most of the principal streets and avenues soon followed, but with the increased demand came competition and numerous attempts to reduce the cost by the substitution of inferior materials and methods, until finally the quality became so poor as to lead to early disintegration. This result became generally noticeable in Paris about 1880, and in consequence of the inability of contractors to make the proper repairs, asphalt pavements fell into serious disrepute.

"In relation thereto, M. Leon Malo, the well known French paving

expert, states that up to 1876 all the asphalt pavements of Paris were built and maintained by said (General Asphalt Co. of France) company and gave entire satisfaction. In that year, however, the contracts expired, and the municipal authorities yielded to the pressure brought by rival paving corporations to open the work of construction and maintenance to general competition, and award the contracts to the lowest bidder. The consequence was that the work was taken at low prices by inexperienced firms and performed improperly. In the course of five years over 240,000 sq. yd. of the inferior asphalt pavement crumbled, and the contractors went into bankruptcy, leaving repairs of enormous extent undone and creating widespread prejudice against this kind of pavement. The authorities then realized that such work could not be done in a haphazard manner, and thereafter gave contracts only to the most experienced and responsible firms, under strict inspection, and limiting the source of bituminous rock to a few quarries of established reputation."

The engineer, then, is confronted with the problem of choosing between tried and untried materials, between materials the composition and characteristics of which have been found to be uniform through a long period of years, and materials the composition of which varies not only with the method of preparation but also with the character of the oil from which the manufactured material is prepared.

On the one hand, there is the natural Trinidad asphalt, the composition of which is thoroughly understood and found to remain uniform. The proper method of handling it has been well established, through years of successful use, and it has been proved beyond contention, by actual service tests, that under given conditions it may be absolutely relied upon to give good results.

On the other hand, there are the materials falling under class B, noted above. On account of the method of preparation, extreme care is necessary to produce desirable results, and there are many opportunities for spoiling the product through lack of skill in preparation. Excellent results have been obtained with some of these products when carefully prepared, but the fact remains that, as a rule, the product is not uniform and has not been used for a long enough period under known conditions to have demonstrated its durability in a pavement. Materials under class C are produced under such peculiar conditions, and from such a variety of materials, that the product is far from uniform. None of these oil asphalts has been in use sufficiently long to demonstrate its wearing qualities.

It may be urged that, with the present system of elaborate

and accurate physical and chemical tests, an engineer is able to differentiate between the good and the poor bituminous material; that if the material satisfy these tests it is sufficient evidence that it is fit for use, and that, therefore, there is no great necessity for demonstration of excellence through long periods of service. Certainly, by chemical and physical tests, an engineer can determine the qualities possessed by certain bituminous material. But what indication has he that this material will retain these desirable characteristics through a long term of years, when subjected to traffic and to climatic changes? Possession of desirable characteristics is to be commended, but lack of retention makes the material worthless. Until a successful standard accelerated test shall have been devised in which actual conditions of service are reproduced, an engineer must rely on service records to determine the lasting and wearing qualities of the material under examination.

Moreover, having determined the physical and chemical properties of a given material, by what standards can an engineer judge the fitness of this material for use? Obviously not from tests on other, totally different, materials. Tests are invaluable in determining the presence of certain qualities in a material, but must be interpreted with discretion in predicting the future behavior of the material in a road, unless material of the same character, prepared in the same way, and possessing the same qualities, has already proved successful in use.

Furthermore, engineers are not agreed on the character of tests to be made. One authority (E. M. Perdue) states that it makes no difference what the origin of the material is, whether it come from Trinidad Lake or Oklahoma, or is the product of distilling an asphaltic, semi-asphaltic or even a paraffine petroleum; the only requirement is that the asphalt cement have the "proper" ductility, viscosity, and penetration. Another authority sees no value whatsoever in chemical tests and places entire reliance on certain selected physical tests. Still a third authority (Hubbard) believes that the chemical are even more important than the physical tests. An engineer, usually possessing but a limited knowledge of bituminous materials, must therefore have a safer and more accurate guide

for his selection of materials, and that guide is to be found in judicious interpretation of service records.

With the elimination of the long-term guaranty clause, an engineer is now confronted with the question as to the advisability of restricting competition, or of using untried materials; for the natural Trinidad and Bermudez, and some few of the manufactured asphalts, are the only materials which have been in use long enough, and under a sufficient variety of traffic and climatic conditions, to furnish reliable service records.

If he selects from tried materials only, which, under known conditions of traffic and climate, have given entire satisfaction, he is certain that any surface which he lays will succeed, provided standard methods of construction are followed, and proper care and attention are given to the selection and grading of the mineral aggregate. Physical and chemical tests of the selected asphaltic material will be valuable to him, not in predicting what may be expected of it, but in identifying it as material of the same physical and chemical character as an asphalt which is known to have been successful under given conditions. Although this practice is certain to yield satisfactory results, it is open to two objections: (1) by limiting competition to that class of materials the fitness of which has been established by long use, it fosters monopoly, with the attendant danger of high prices, collusion, or fraud; (2) it renders impossible the experimental introduction of a material which might ultimately prove superior to the favored ones, and possibly cheaper, thus delaying real progress towards the attainment of a satisfactory cheap pavement.

If, on the other hand, an engineer admits all materials, disregarding service records and basing his choice merely on the price bid, trusting entirely to carefully drawn specifications and laboratory tests of the material, he may reduce the first cost, but he has no assurance that the pavement will not be an expensive and total failure. To be sure, he is contributing to the advance of engineering knowledge, and is perhaps giving needed help to a friendly concern in trying out a new material, but it is a question whether he is justified in jeopardizing the interests of the municipality which he serves in order to help launch a new, possibly worthless, possibly excel-

lent, material on the market. The desire of an engineer to advance the art of street paving, while also affording an equal opportunity for all bidders to obtain work, is commendable; but failures in street surfaces entail so much financial loss and inconvenience to a community that it is nevertheless advisable for an engineer to subordinate his altruistic ideas to the interest of those whom he serves.

The situation is a difficult one, and many solutions have been suggested. The writer claims no originality in the suggestions herewith offered, but presents them, with some original modifications, as a possible solution of the problem.

In preparing specifications and awarding contracts, each street should be considered as a separate unit, and the special conditions of traffic, character of abutting property, and location and importance of the particular street to be paved, should be controlling factors. If the street is an important one, where interruption to traffic through frequent repairs, or entire resurfacing because of total failure, would result in heavy financial loss to the city and to abutting property owners, choice of materials should be limited to those which, by experience, have fully demonstrated their fitness for use under the particular conditions existing in that street. Competing contractors should be compelled to submit certified proof of service records, and these records should be given more weight, in awarding the contract, than the consideration of price. On all streets of less importance, open competition might be permitted, with the inclusion of a modified form of guaranty clause. The contractor should be required to submit a price per square yard for laying the surface only, and a separate price for repairing during the first, second, and third five-year periods, the engineer being free to award the contract with or without the clause covering repairs.

In every case, whether selection of the material be restricted or whether open competition be permitted, the "reverting specification" recently advocated by H. P. Pullar (*Eng. Rec.*, April 4, 1914, p. 393, and May 2, 1914, p. 515) is to be recommended. Under this specification, "At the time of awarding the contract the successful contractor will state what bituminous material he will use, and will agree to use an asphalt complying with a specification for that particular

class or brand of material. The contractor——would——have to supply a bituminous material complying with a strict specification and one which could take under consideration the local conditions."

The carrying out of these suggestions would permit the use of tried and safe materials only, on important streets; but would also afford opportunity to the introducers of a new material to compete fairly with companies supplying a standard material, and thus enable them to demonstrate the properties of their asphalt by actual service, but with less loss to the municipality in case of failure.

In closing, it may be pointed out that the success of any plan that may be advocated will depend largely on the removal of purely technical and engineering matters from the control of lay bodies and commissions, on the thoroughness of the engineer's knowledge of paving methods and materials, on his ability to co-ordinate the results of laboratory tests with interpretation of service records, and above all on his close adherence to a high standard of professional ethics.

HEATING VALUE OF EXHAUST STEAM.

BY DAVID MOFFAT MYERS.†

In my work with factory power plants I have found that efficient utilization of exhaust steam is very commonly a determining factor in the over-all economy of a plant. Consequently the heating value of exhaust steam has received careful consideration, both as to its actual application in practice and also as to the calculation of its amount from given data. To the latter aspect of the problem this paper will be principally directed. I have endeavored to develop the subject in such form as to make the data of direct value to contractors and heating engineers, for the laying out of systems which shall fulfill the predicted expectations.

It should be needless to state that the weight of steam and moisture issuing from the exhaust of an engine is equal to the weight of the steam and moisture entering the throttle of the engine. We are therefore interested only in the thermal and physical condition of the fluid mixture as it leaves the engine. Thus, if we could conceive the impossible, i. e., that its condition is the same at the exhaust as at the throttle, then the heating value of exhaust steam would precisely equal that of live steam.

There are only two ways in which heat is abstracted from steam in passing through an engine, and all heat not so deducted appears in the exhaust in the form of steam or hot water. These two ways are:

1. By conversion of a part of the heat into mechanical work.

2. By dissipation of a small amount through cylinder radiation.

Hence if we know these factors we may quickly compute the heat which remains in the exhaust. We may further compute accurately how much moisture the exhaust steam mixture will contain. Item 2, radiation, comprises so small a percentage of the total heat in the steam used by the engine that its quantity is negligible. For instance, a 100-h.p. non-con-

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†Mech. E., Columbia, 1901. Consulting engineer, 110 W. 40th St., New York.

densing engine at full rating may use about $100 \times 30 \times 1189$[1] $= 3{,}567{,}000$ B. t. u. per hour. By allowing a radiating surface of say 25 sq. ft. (a too generous allowance, to be on the safe side[2]) and assuming continuous boiler pressure inside the cylinder, the outside air being at 70° F., we may treat the engine cylinder as a high pressure radiator and compute the B. t. u. radiated as follows:

$3^{3} \times 25 \times (339^{4} - 70) = 20{,}175$ B. t. u. per hour. Comparing this amount of radiated heat to the total B. t. u. supplied in the steam to the engine we have: Maximum heat lost in radiation $= 20{,}175 \div 3{,}567{,}000 = 0.00565$, i. e., a little over 0.5 per cent.

Since, as explained in the foot-notes, the assumed radiation data are purposely too generous, the actual radiation loss will be much smaller even than the above estimated percentage. Therefore, for commercial purposes, this loss may be entirely neglected.

In further confirmation of the above statement, in the Proceedings of the American Institute of Electrical Engineers, vol. 25, 1906, H. G. Stott states, referring to engine radiation losses, "This source of loss has evidently been reduced to a negligible quantity by the use of improved material and methods of heat insulation."

In the heat balance given in Mr. Stott's paper, the radiation losses are recorded as 0.2% of the heat of the coal. If the engine received 70% of the heat of the coal in the form of steam, then the radiation loss amounted to 0.00286; that is, less than 0.3% of the heat entering the engine.

We have now only to consider the abstraction of heat from the steam which is converted into mechanical energy. This loss of heat varies in inverse ratio to the efficiency of the engine. That is to say, the more efficient the engine the less

[1]Heat in 1 lb. of steam at 101.3 lb. pressure.

[2]A 14 x 20 engine is assumed and the outside covering of a rectangular cylinder lagging is figured as radiating surface. This surface is figured as being surrounded on its outer surface by air at 70° and its inner surface to be supplied constantly with live steam at boiler pressure. Of course, the average internal temperature of the cylinder would be much lower than this, and the actual radiating surface would be much less than that assumed.

[3]Coefficient of radiation assumed at 3 B. t. u. per sq. ft. per degree difference per hour. This coefficient is too high (so taken purposely) since the cylinder is usually lagged and not bare, as assumed.

[4]339°—temperature of dry saturated steam at 101.3 lb. pressure.

will be the heat contained in the exhaust steam mixture. It is now necessary only to know the amount of heat in a pound of steam entering the engine, and the efficiency of the latter, referred to indicator horse-power, to determine the heat in 1 lb. of its exhaust steam mixture. The former quantity depends upon the temperature and pressure of the entering steam, and the efficiency upon the steam consumption of the engine.

For example, take the following data:

Dry saturated steam at throttle, pressure.....103.3 lb
Temperature, F.....338.7°
Steam per indicator horse-power hour.....25 lb.
Heat in 1 lb. of entering steam (above 32°).....1189 B.t.u.
Thermal efficiency of engine at above steam rate.....8.56%[5]

The heat remaining in 1 lb. of the exhaust mixture will therefore be $(1.00 - 0.0856)1189 = 1085$ B. t. u. above 32°.

We may simply state that the total heat in a pound of exhaust mixture is equal to the heat in a pound of the steam at the throttle minus a percentage equal to the thermal efficiency of the engine (disregarding the negligible radiation loss). Stated as a formula we have:

$$H_e = H_s \times P \qquad (1)$$

in which H_e = total heat above 32° in 1 lb. of exhaust mixture. H_s = total heat above 32° in 1 lb. of the steam supplied at throttle. $P = 1.00$ (thermal efficiency of engine referred to indicator horse-power and expressed as a decimal).

Now the form in which this heat is carried vitally affects our problem. That is, we must know what percentage of the exhaust steam mixture consists of water of condensation. After the total heat in the exhaust mixture is determined as above, its moisture content depends upon the back pressure in the engine.

To carry out our specific example, let us assume the engine in question to be operating against a back pressure of 3.3 lb. gauge, measured close to the exhaust ports. The steam portion of the mixture will then contain 1154.2 B. t. u. per lb. (above 32°) and the moisture portion, which will be at a temperature of 222.4 (temperature of steam at 3.3 lb. gauge) will contain 190.5 B. t. u. per lb. Let x =weight of

[5]Efficiency referred to indicator horse-power = output ÷ input = 2545 ÷ 25 x 1189 = 8.56%.

steam in 1 lb. of exhaust mixture. Then $1 - x =$ weight of water in 1 lb. of exhaust mixture. Then the heat in 1 lb. of exhaust mixture, 1085 B. t. u. $= 1154.2x + 190.5\ (1 - x)$. Solving:

$$x = 0.927 \text{ steam (lb.)}$$
$$1 - x = 0.073 \text{ water (lb.)}$$

Hence the exhaust mixture, per pound, contains 0.073 lb. of moisture. The steam portion, 0.927 lb., contains 1154.2 B. t. u. per lb., a total of 1070 B. t. u.

If we term as useful exhaust that portion which consists of steam without moisture, the useful exhaust heat from our engine will carry 1070 ÷ 1189 or 90% of the total heat of the steam which entered the engine in this instance.

The following formula covers the calculation for the weight of dry saturated steam contained in 1 lb. of the exhaust mixture for all cases.

$$W = \frac{H_e - H_w}{L} \qquad (2)$$

$W =$ Weight of dry saturated steam in 1 lb. of exhaust mixture.

$H_e =$ Total B. t. u. in 1 lb. of exhaust mixture as previously defined.

$H_w =$ B. t. u. in 1 lb. of water at the temperature of exhaust steam.

$L =$ Latent heat, B. t. u., of steam at the pressure of the exhaust.

The deduction of this formula, denoting the total heat of dry saturated steam at the exhaust or back pressure as H_b, is as follows:

$$WH_b + (1 - W)\ H_w = H_e$$

Simplifying, we have:

$$W = (H_e - H_w) \div (H_b - H_w).$$

Now, since $H_b - H_w = L$, we have

$$W = (H_e - H_w) \div L.$$

This simple method of determination may be applied to any set of engine conditions and may be relied upon for accurate results. The appended exhaust steam curves have been constructed in this manner and are here presented with a view

to furnishing a convenient reference for the use of heating and ventilating engineers.

It is to be noted that the present curves are for dry saturated steam at the engine throttle, though, of course, by the same method of calculation they may be made to include both superheated steam and steam containing moisture.

From an analysis of formulas 1 and 2, it will be found that the percentage of the heat of the initial steam which will appear as dry saturated steam in the exhaust (that is, the result we desire, which we may term R%) obeys the following laws as to its variation.

Changing the back pressure:

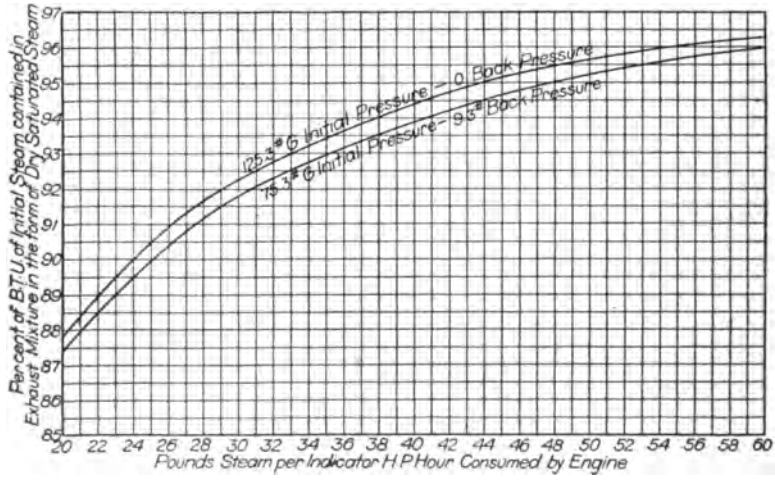
Increasing the back pressure lowers the R%.

Reducing the back pressure raises the R%.

Changing the initial pressure:

Increasing the initial pressure raises the R%.

Reducing the initial pressure lowers the R%.


Percent of B.T.U. of Initial Steam contained in Exhaust Mixture in the form of Dry Saturated Steam
97
96
95
94
93
92
91
90
89
88
87
86
85
125 # G Initial Pressure — 0 Back Pressure
15 # G Initial Pressure — 9.3 # Back Pressure
20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60
Pounds Steam per Indicator H.P. Hour Consumed by Engine

If, therefore, we lay out one curve, representing maximum initial pressure and minimum back pressure, and anther courve for minimum initial pressure and maximum back pressure, all the other possible values of R% will lie between these two curves for any other combination of initial pressure and back pressure the values of which lie between the selected extremes.

In order to cover practically all ranges of application, I have

plotted the first or upper curve for 125 lb. (gauge) initial pressure with zero or atmospheric back pressure, and the second or lower curve for 75 lb. initial pressure with 9.3 lb. (gauge) back pressure. It will be noted that within this range any changes in initial and back pressure will affect the result no more than 0.6 per cent.

To apply these curves for results within this degree of accuracy, it is necessary merely to know the steam consumption of the engine per indicator horse-power per hour, and the steam pressure at the throttle. If still closer results are wanted, the back pressure should also be known, but since heating calculations are susceptible to errors which are huge in comparison, the heating engineer need only know that the back pressure does not exceed 9.3 lb. in order to get results from these curves. The results obtainable in this easy, simple manner, are, as stated, accurate to within 1%. Greater accuracy, if desired, can be obtained (barring the negligible quantity of radiation) by careful application of formulas 1 and 2 herewith deduced.

It is, perhaps, hardly necessary to state that the results in the use of exhaust steam in actual practice closely agree with these determinations of heating value. Any engineer who has had the opportunity to make observations with actual measurements, has found that exhaust steam from a simple engine is worth, for heating purposes, nearly as much as live steam. I have myself been fortunate in having had opportunities for this kind of measurement. I might mention one case where several slide-valve engines were used to furnish power of which the exhaust steam was absorbed by the heating system in a large manufacturing concern. The exhaust steam just satisfied the heating requirements at the time of the year when I made my experiment. I shut down all the engines in the plant and supplied the heating system by using live steam at reduced pressure. The fuel was carefully weighed, and it was found that just as much was consumed during the test with the engines shut down as when all the engines were developing their full quota of power. This experiment was made for the purpose of supplying a practical demonstration which would appeal to the minds of an executive committee of a large corporation, who believed

that it would pay to shut down the steam engines and replace them with producer gas engines, and could not understand that exhaust steam contained within a few per cent. as much heat as live steam. I have made other tests which have checked these results closely.

The curves presented herewith cover practically all cases of engines the exhaust of which might be used for heating purposes, the range covering steam consumptions, per indicator horse-power per hour, from 20 lb. to 60 lb.; and in order to facilitate the use of the curves the following table of steam engine consumption is given.

For dry saturated steam, pressure range 75 lb. to 125 lb. gauge, back pressure range 0 to 9 lb. gauge, steam consumption of engine will vary as follows, depending upon the special combination of these factors, percentage of full load, and upon the physical condition and detailed design of the engine.

Type of Engine	Steam per I. H. P.-Hour—Non-Condensing	
	Range	Average
Slide-valve, throttling governor, simple engine	35 to 75	50
High-speed automatic cut-off governor, simple engine	28 to 57	35
High-speed, four-valve non-releasing gear, cut-off governor	25 to 45	33
Corliss, regular type releasing gear	23 to 35	30
Corliss, compound releasing gear	20 to 30	25

The steam consumption of an engine varies so widely with the variables noted, and also with the size of the engine, that this table must be used with discretion. The best way to obtain the true steam consumption of an engine is to test it by weighing the feed water to the boiler which supplied it, cutting out, of course, all other steam consumers during the test.

We have now developed sufficient information for the easy and accurate determination of the heat in the exhaust steam from engines, but to make this paper more nearly complete we must add some matter relating to steam pumps, since from this source a very large amount of exhaust steam may be supplied for heating. From tests which I have made, it is safe to calculate that a duplex boiler-feed steam pump will consume from 5 to 7% of the total steam generated in the boilers which it supplies. I have further calculated that such pumps have an efficiency corresponding to about 237 lb. of

steam per indicator horse-power per hour. Applying formulas 1 and 2, we shall find (boiler pressure 115 lb.) that R% = 99.5% with 0 back pressure.

For ordinary small sized boiler-feed pumps, therefore, we may safely say that the pump takes out not over 1% of the heat of the steam which is supplied to it, and the steam consumed by such a pump amounts to approximately 6% of the steam generated by the boilers which it feeds.

Steam pumps of this type, but used for other purposes, will also exhaust about the same percentage of useful heat as related to the steam which enters them. Hence for the same amount of work (based on indicator horse-power hours) the ordinary steam pump consumes about eight times as much steam as a Corliss engine. Based on brake horse-power or actual work performed, the pump is still more wasteful in comparison with the engine.

These data are given merely to attract proper attention to the very large amount of heat which is made available in the form of exhaust from steam pumps. This must be computed as shown, and added to the heat of the engine's exhaust in order to produce a complete estimate of the total available heat in the exhaust steam. Without such an estimate beforehand, no heating project can have those qualities of certainty and efficiency which have always distinguished engineering from guesswork.

DIE-CASTING OF WHITE ALLOYS.

BY JOHN C. WORK.

In 1908 the author was called upon to take charge of a die-casting business for the manufacture of small parts of various machines and appliances which ordinarily required a good deal of machine work. The process by which these parts were to be made was supposedly a secret one, which had been brought from France by a Frenchman who had worked for several years in a plant engaged in similar work.

Abroad, according to the best information obtainable, this plant was turning out not only small articles made of white metal, but had even succeeded in casting aluminum crank cases for automobile engines which were so perfect that they could be fitted together without any machine work whatever. Although this state of perfection was never realized in our work, many small articles were successfully cast in white metal, accurate to 0.002 in. While this is being done at the present time by several small concerns, the most important of which is the Franklin Die Casting Co., at Syracuse, the process used by them calls for the application of pressure to the molten metal in order to force it to fill the moulds completely. The French process, with which the author was connected, did not require any pressure other than that afforded by approximately a 6-in. riser in the die itself.

The chief reason for the lack of financial success of our company was the inability of the French workmen to realize the value of time in American business methods, coupled with lack of capital to install the apparatus which experiments led the management to believe necessary.

While the actual composition of the alloy used in France was supposed to be a profound secret, known only to the one Frenchman who brought it to this country, the author found that any of the numerous so-called "white metal" alloys, such as are given in Kent or similar handbooks, may be cast satisfactorily to the above mentioned accuracy, with a very small percentage of failures. The intricacy of the casting appears to be limited chiefly by the skill required in the manufacture of the die.

The die should be made from highest grade, gray cast iron. The workmanship must be of the very best quality, and all the parts going to make up the complete die must be capable of being taken apart and assembled with a minimum amount of labor. They must have numerous vents to permit the escape of gas from the cooling metal.

A good deal of the success in making castings seemed to lie in having the molten metal at the correct temperature; if too hot, it did not seem willing to take the exact form of the mould, and if too cold it would not flow with sufficient freedom to fill the intricacies. If poured at the right temperature, there was no trouble in casting the thread on bolts from 1/8-in. diameter up.

Before pouring the metal, the moulds were heated, and then plunged into a tub containing water and whiteing, which was kept in a state of suspension by stirring. This dipping was followed by another heating of the moulds. When the moulds had reached a proper temperature, which was entirely a matter of judgment on the part of the man handling them (testing the temperature as a woman tests the heat of a flat-iron), the metal was poured. The small castings, which were most successful, cooled enough to be taken from the mould in a very few minutes. This process was repeated, dipping the moulds after every three or four casts.

One of the chief fields for this class of work was originally thought to be in the carburetter line. While we were quite successful so far as turning out the parts and fitting them was concerned, no one realized, or knew from experience with the metal used, the effect of gasoline upon it. While in the liquid state, gasoline apparently had little or no effect, but when vaporized, or when just vaporizing at the spray plug, it acted on the metal with the formation of a white deposit. This deposit was never analyzed, but much resembled zinc oxide in appearance. This deposit rapidly caused the suspension of ignition and the entire carburetter had to be taken down and cleaned. In the small plant, and using hand moulds, we were never able to cast an alloy running high enough in aluminum to make any material difference as to the effect of gasoline vapor.

While the author does not believe that aluminum in any-

where near a pure state can be cast in dies without using pressure, he believes that with proper ovens in which to heat the dies, and with the use of pressure to force it into them just at the moment of solidification, die castings can be made which will far surpass in accuracy any aluminum castings yet produced.

A few attempts were made to cast brass in dies, but they were not satisfactory. While occasionally a perfect thread would be obtained, there was apparently too much gas in the metal. This trouble was lessened, but not wholly overcome, by increasing the number and size of the vents in the die.

After a considerable amount of experiment had proved that the die-casting process, as carried on, was not particularly satisfactory, chiefly owing to the expense of making the dies for small orders, this end of the business was abandoned, and the shop converted into a brass foundry.

CAMP COLUMBIA IN 1914.

BY JAMES K. FINCH.

In the spring of 1914 the summer school of surveying, at Morris, Conn., was placed under the direction of the Summer Session, Professor James C. Egbert, Director. The school was first located near Litchfield by Prof. H. S. Munroe, of the Department of Mining. In 1891 the present location was selected; later on the property was purchased and the camp came under the supervision of the Department of Civil Engineering. In 1897 Earl B. Lovell, Professor of Civil Engineering, was given charge of the camp and it remained under his direction until last spring. Started merely as a camp of tents with an old farmhouse as the "headquarters" and dining room, with a short session and only a few students, under Prof. Lovell's able and skilful administration it has grown to a property valued today at over $75,000, representing land, buildings and equipment second to none for this kind of work. During most of these years, Prof. Lovell spent the entire summer in actively directing the work of instruction and expansion, and built up a school of surveying, organized on a broad and practical basis, the work of which is so thorough and comprehensive that it has achieved a wide reputation.

The change in administration was made by the Trustees because they felt that the opportunities and advantages of the camp were so great, and that it was such an important factor in the life of the University, that its activities should be extended so as to make it possible for college and other students to attend; also, that this could be accomplished more readily by the Summer Session than by a departmental administration. Following out this idea, two new courses will be offered during the coming summer, in geology and botany, and it is hoped that students in Columbia College will give this work their loyal support and assist in making Camp Columbia a still greater factor in the work and student life of Columbia.

The organization and work for last summer, which opened on May 30 and closed on Aug. 31, a session of thirteen weeks, was along the same lines as in the past. The work

in plane surveying was in charge of the writer, assisted by Gilbert D. Fish, C.E., '12, who had charge of the leveling and repetition surveys; Elwin H. Findlay, C.E., '12, under whose care the freshmen made their usual pacing and farm surveys; W. J. Krefeld, C.E., '14, had charge of the work in highway and hydrographic surveying as well as the instrumental equipment. Students were advised that "every little contour has a meaning all its own and every hill and valley by some 'tope' sign must be shown" by W. W. Havens, C.E., '14, who also had charge of some new work in sanitary engineering offered last summer for the first time. W. C. Ohlssen, C.E., '14, took charge of all city surveys, while Roy V. Wood, Met.E., '14, and "Coxy of The Crew" directed the transportation of plane tables in points of topographical advantage, and acted as consulting engineer in the location of some promising (?) mine claims. The astronomical work again lured Prof. Jacoby from the summer session in New York for week-end conferences with Mr. Bowie and the rest of the faculty. Mr. Bowie, who has charge of the Division of Computations and is Inspector of Geodetic Work for the U. S. Coast and Geodetic Survey, has become a fixture at the Camp, we hope, and also the acknowledged champion at pitching horse-shoes. He was ably assisted by Mr. E. F. Church, of the Coast Survey, and Mr. Fish also assisted in the triangulation work. The writer was relieved of a large part of the detail work of administration, which was under his charge as Resident Director, by D. L. Dunbar, '15, College, who also acted as official photographer.

Among the visitors during the summer were Dean Goetze, Prof. Egbert, Mr. Pine and Mr. Lawrence, Prof. Pupin, Chaplain Knox, Mr. Perrine and Mr. Danielson. A number of alumni and students were also at Camp: O. K. Hand, '83, Lindsley, '97, F. Mason, '98, W. T. Derleth, '04, R. deC. Greene, '06, G. E. Beggs, K. M. Boorman, A. C. Kaestner and G. E. Strehan, '10, T. E. King, '11, C. F. MacCarthy, '14, and R. C. Barnaby and W. White, '15. We were particularly pleased to welcome Prof. J. L. Greenleaf, '80, who visited Camp after an absence of about 20 years, and who at one time was in charge of this work. Dean A. W. Fuller of the University of Washington also spent a few days at Camp and was duly initiated

to the Order of the Bath at a special meeting held in the Wash House one cold morning. A number of parents also looked up the summer school and seemed pleased with the work and surroundings.

The installation of a wireless receiving station, the object of which was to enable the students in geodesy to obtain the time signals sent out every morning from the government station at Arlington, near Washington, and thus determine the longtitude of the Camp, brought to light a number of wireless experts and enabled us to get the results of the boat races at Poughkeepsie about twenty minutes after each race, as well as the baseball and other news every evening. Another electrical installation, brought about by the generosity of a college alumnus, enabled us to light the entire camp with electricity with power furnished by the Bantam power house of the Litchfield Electric Light and Power Co. The safety and convenience of this system, in comparison with the old kerosene lamps, make it without a doubt the most important improvement of recent years, and we are one and all indebted to the donor. We also built a boathouse on Bantam Lake, with a dressing room and equipment of boats and canoes, from part of the same gift, which was so liberal that we were also enabled to complete the baseball diamond and repair and paint the farm house.

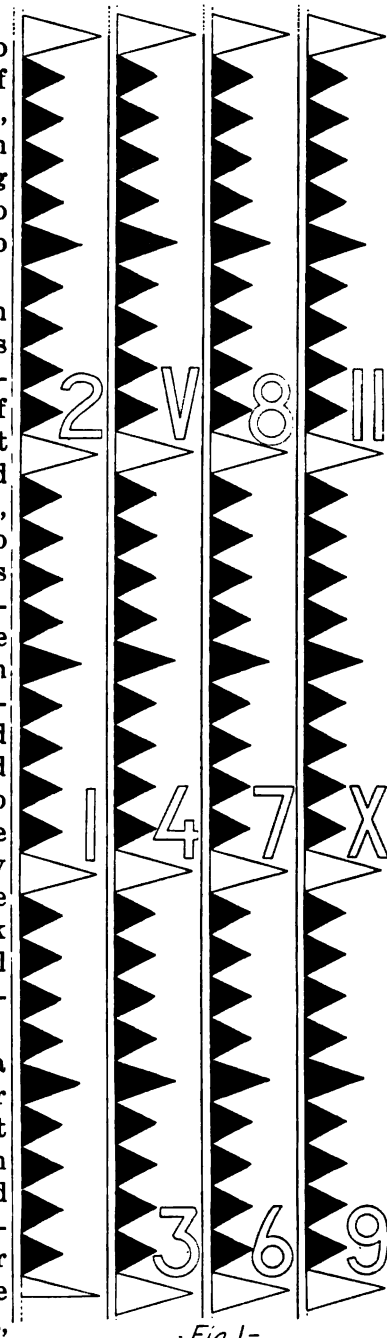
Student activities at the Camp were given a great impetus when we found, as we all felt would happen, that the crew had won at Poughkeepsie. All the instructors and 160 students worked all the afternoon of June 25 in building the largest fire we have ever had for "Crew Night" and the student board had the beer and other refreshments in charge of a capable commissary department. The next day the entire Camp paraded to Litchfield and hoisted the Columbia flag on the green, where speeches were delivered by prominent citizens who seemed to know what it was all about and just how we felt.

A minstrel show given at Litchfield and Morris, and a regatta on the lake, were successfully conducted by H. J. Wieler, P. & S., our energetic Y. M. C. A. Secretary, and the summer was brought to a close by the annual railroad dinner which was turned into a crew celebration and general round-

up. Everybody who could do anything performed, and four of the crew, Hadsell, MacCarthy, Wood, and Bratton, were with us. The speech of the evening came from O. K. Hand, '83, who said a little that meant much to us all.

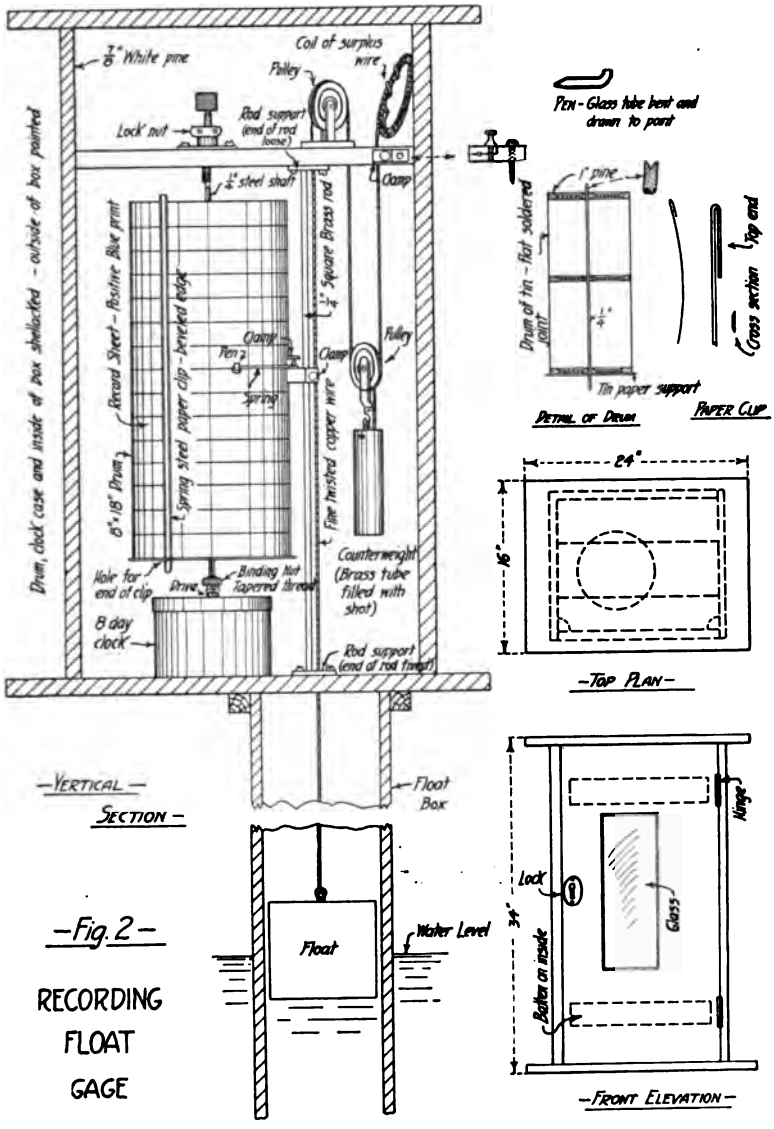
In regard to the instruction in survey work a few additions were made. A course was offered at Camp on the theory of plane surveying for the first time, and a laboratory and field course in Sanitary Engineering, known as Limnology, was also given. The latter work was made possible by building a laboratory near the boathouse which was fully equipped with filters, sterilizer, oven, microscopes, etc. Samples of lake and well water were analyzed, and resulted in our being able to warn several camps which were receiving their water supply from the same well that the water was dangerous. The work was new and interesting and will be continued and perfected during the coming summer.

Fig. 1 gives the details of a new idea for stadia rods. After trying a number of patterns it was decided to adopt that shown in the cut, which is the one used by the U. S. Geological Survey. This pattern is far better than that used on the so-called Florida and other rods,



-Fig 1-

which are frequently so complicated, and so dark in color and lacking in contrast, that they cannot be used to advantage on a dark day nor for long sights; furthermore, it is very simple,



-Fig. 2-

RECORDING FLOAT GAGE

as it does not involve any complicated geometrical figures or peculiar dimensioned numerals. The contrast between the white

field and the black markings makes the rod stand out clearly at any reasonable distance. A full-size tracing of this pattern was made and a number of black prints on extra-heavy paper were obtained from E. G. Soltman, N. Y. The outlined numerals and foot marks are filled in with red. The strips may then be cut out and used for making new or repairing old rods. One face of the rod is covered with shellac or varnish and the strips are placed, properly registered end to end, dry upon the wet surface and weighted until fixed in place. It is best not to wet the strips themselves, as the shellac may soak in and render them more or less transparent, or the scale may be distorted. The pattern may finally be shellaced or varnished to protect it from the weather. In making a tracing for the pattern it is best to use tracing cloth about 40 in. wide and draw the pattern across the cloth, as cloth shrinks but little transversely while new cloth may change considerably longitudinally. This inexpensive method of making a rod is very convenient where transportation is difficult, as the pattern may be tacked on to any board or even a small tree split in two, and, when the work is finished, can be thrown away.

Fig. 2 gives the details of a recording float gage, two of which were constructed at a cost of $15 each. Most of the gages on the market cost from $75 to $200. The clockworks for driving the drums were purchased from the Draper Mfg. Co., 152 Front St., N. Y., for $5 each, and may be obtained with proper gearing for revolving the drum once in a day or a week, as required. The diameter of the drum may also be varied so as to give any desired length of record per hour or day. Ink can be obtained from the Draper Co., who also makes pens. This gage is very easy to set, as it may be placed at any level and the fine, copper, float cord adjusted to the requirements.

FLOTATION TESTS ON ORES FROM BISBEE AND COBALT

BY HERBERT J. FRENCH.

For the purpose of this investigation, five variable factors were considered, no one of which is entirely independent of the others:

1. Oil
   a. Variety of oil
   b. Amount of oil
2. Amount of acid (only sulphuric acid used)
3. Agitation
   a. Length of agitation
   b. Speed of agitation
4. Temperature of solution.
5. Size to which ore is crushed.

The effect of variations of each one of these factors upon the extraction of metallic mineral was investigated in turn, and having experimentally found the best condition for the first factor, this was kept constant, and the second variable then considered. In performing the experiments, however, it was necessary to deviate slightly from this system, but the results obtained from the experiments as performed gave equally satisfactory results.

The machine employed in the following tests was improved to its present form by the Minerals Separation staff, and was given to the School of Mines by James M. Hyde. The driving mechanism was a 1/16-h.p. motor connected to a 110-volt line through a variable resistance. The machine, and its operation are fully described in Hoover's "Concentration of Ores by Flotation", Chap. V.

The method of making a test is as follows: Fill the machine with water to a level slightly above the middle. (If it is desired to heat the solution, repeatedly pour boiling water into the machine until the walls have become hot and then fill with water which is near the desired temperature). Add the ore and agitate for a few seconds until thoroughly wetted. When the ore and water have reached the desired temperature, heat being obtained from Bunsen burners, add the acid in the proper proportion. Next add the required amount of

oil and turn on the motor, bringing it gradually, but quickly, to full speed by means of the variable resistance. After the required agitation, stop the agitator and allow the emulsion to settle for about one minute to allow time for the froth to collect on the surface of the water and for the gangue to settle. The upper part of the machine is then slid along the plane of contact, carrying with it the froth and that portion of the clean water above the plane of junction of the two parts, and discharging them into a pan. This process may be repeated on the tailing, without or with the addition of more oil; but before further agitation, water should be added to just above the sliding plate. The tailing and remaining water are then withdrawn into a pan, through the bottom spigot, allowed to settle, and the greater part of the water decanted. The tailing is then dried, screened, mixed, sampled, and finally assayed or analyzed.

Treatment of Bisbee Porphyry Ore

The ore used in the following tests was mined at Bisbee, Ariz., and is porphyritic; under the microscope it shows a variable texture from fine to medium. The copper in the ore exists almost wholly as cupriferous pyrite, black sulphide (chalcocite) and malachite. Its analysis is: [1]

SiO_2 (insoluble)	65.10%	
Fe	10.90	
CaO	0.90	
Al_2O_3	0.28	
Total Cu	6.04	1.70 soluble in dil. HCl
S	12.70	4.34 insoluble

Only a small part of the copper in the ore is in soluble form; hence, before a leaching process can be applied the ore must be given an oxidizing roast. Roasting an ore is an expensive operation; whence it is desirable to test the applicability of flotation to that part of the copper existing as sulphides. If found possible, the ore may then be divided into two parts—one consisting mainly of sulphides which may be smelted directly, and a second part which may be leached directly for its copper content. [2]

[1] Ph.D. Thesis by R. R. Goodrich, Columbia University, 1915.

[2] That this portion of the ore may be satisfactorily leached has been proved by R. R. Goodrich, "Hydroelectrolytic Treatment of Copper Ores." Ph.D. thesis, Columbia, 1915.

After testing the ore in the machine, as above described, the tails were analyzed for S, whence the percentage of extraction of the sulphides could be computed. The method of analysis was as follows:

To 1 gm. of finely ground tailings add 15 c.c. of a saturated solution of $KClO_3$ in concentrated HNO_3. Evaporate to dryness. Add 5 c.c. concentrated HCl and heat till no more Cl is evolved. Add 10 c.c. HCl and 15 c.c. water, boil for 5 min., filter, and wash. To the hot filtrate add $BaCl_2$. Allow to settle, and filter. Ignite precipitate and weigh. $BaSO_4 \times 0.13738 = S$ equivalent.

Variation of Oil.—Several oils, such as fish, sperm, whale, corn, cylinder, pine, pine-tar, lard, and cottonseed, were tried under fixed conditions. Both qualitative tests, by shaking oil, acid, ore, and water in test-tubes, and quantitative tests on the machine, were made. Of those oils available it was found that pine-tar oil gave the maximum extraction with a minimum weight of froth. Pine oil and fish oil both gave good results, but the froth, in addition to being of non-selective character, did not seem so lasting with either of these oils as that given by pine-tar oil. The character of the froths obtained by the other oils mentioned above did not seem to indicate successful operation; hence the pine-tar oil was selected as the most desirable.

The oil was next varied in amount from 0.5 to 6 gm. The runs were made at room temperature on 100 gm. of ore, and using 35 drops of concentrated H_2SO_4 in 1500 c.c. of water. The period of agitation was 3 min. and the tailings from each test were analyzed. The results are given in Table I.

Table I. Effect of Variation in Amount of Oil.

Pine-tar oil. 100 gm. ore. 3-min. agitation. Room temp. 35 drops H_2SO_4. 1500 c.c. water. Analyses on 1-gm. sample.

Wt. of Oil, gm.	Wt. of Froth gm.	Wt. of Tails, gm.	Wt. of $BaSO_4$ gm.	Wt. of S, in Tails from 100gm. Ore	% S in Tails	% S Extracted
0.5	3.5	97	0.8624	11.85	93.2	6.8
1.0	4.0	97	0.8610	11.81	93.0	7.0
1.3	4.5	97	0.7480	10.27	80.8	19.2
2.0	10.0	92	0.7290	10.00	78.7	21.3
2.5	11.5	91	0.6885	9.46	74.5	25.5
3.1	12.0	90	0.6308	8.66	68.3	31.7
4.0	13.0	91	0.6182	8.5	67.0	33.0
6.0	20.0	86	0.5329	7.3	57.5	42.5

It is readily seen that as the amount of oil is increased the extraction of the sulphides is also increased. A certain point, however, is reached beyond which more oil does not increase the extraction sufficiently to warrant its use in larger amounts. It is also evident that with increase of oil, other conditions being the same, more of the gangue floats. In other words, the action of the oil becomes non-selective with increase above a certain point. This, as will be shown later, can apparently be counteracted by the proper proportioning of acid and other factors. It will further be noted that the percentage of extraction of sulphides is discouragingly small. This was ascribed to two causes: (1) Insufficient agitation. (2) Improper crushing and sizing of the ore.

It was impossible, with the driving unit available, to create what would seem to be a sufficiently high speed of agitation. It was therefore thought advisable to continue the tests on 50 gm. of ore instead of 100 gm. as used previously. It will also be shown later that proper sizing of the ore is of great importance to the successful operation of flotation concentration.

2. *Variation of Acid.*—As will be seen from the analysis, the ore contains but a small amount of carbonates; hence the amount of acid would seem to play a rather small part in these experiments. For this reason only five tests were made, as recorded in Table II.

Table II. Effect of Variation in Amount of Acid.
Pine-tar oil, 3 gm. Ore, 50 gm. Agitation, 3 min. Room temperature. Analyses on 1-gm. samples.

Drops H_2SO_4 in 1500 c.c.	Wt. of Tails gm.	Wt. of $BaSO_4$ gm.	Wt. of S. in Tails from 100 gm. Ore	% S in Tails	% S Extracted.
None	39.5	0.7320	10.10	80.0	20.0
50	29	0.5231	7.17	56.5	43.5
75	41.0	0.4927	6.75	53.1	46.9
100	38.0	0.4147	5.68	44.8	55.2
150	39.5	0.3952	5.43	42.8	57.2

The results show that above 100 drops of sulphuric acid (= 5 gm.), which is a 0.3% solution, the addition of more acid is practically useless. Acid, however, is apparently necessary since, when omitted, the extraction is reduced from 57% to 20%, nearly two-thirds.

3. *Variation in Time of Agitation.*—In this series of tests,

recorded in Table III, the time of agitation was varied from 3 to 20 min. The results of this experiment are not altogether satisfactory, but they do indicate that both extraction and concentration are increased when sufficient time of agitation is allowed. From these results it seems that 10 min. is the minimum for good results. Undoubtedly the time of agitation required for good results depends more upon the variety of oil than upon the other variable factors, for various oils will require, at a given speed and under given conditions, different lengths of agitation to produce a good and lasting froth.

Table III. Effect of Variation in Time of Agitation.

Pine-tar oil, 3 gm. Ore, 50 gm. Room temperature. 100 drops acid in 1500 c.c. water (= 0.3%). Analyses on 1 gm. samples.

Time of Agitat'on Min.	Wt. of Froth, gm.	Wt. of Tails, gm.	Wt. of $BaSO_4$, gm.	Wt. of S in Tails from 100 gm.Ore	% S in Tails.	% S Extracted.
3	19	37.0	—	—	—	—
6	8	48.0	0.620	8.5	67	33
10	20	36.0	0.404	5.53	43.5	56.5
15	16	39.5	0.804	11.0	86.0	14
20	12	44.0	0.503	6.9	54.5	45.5

The apparatus available did not permit speed variations. The peripheral speed used was approximately 15 linear ft. per sec. Had a higher speed been available, the amount of oil could probably have been reduced, and the extraction would undoubtedly have been increased.

4. *Variation of Temperature.*—In this series, oil was increased above that used previously, to see if a higher degree of concentration could not beeffected. The temperatures were varied from about 25° to 65°C. Results are recorded in Table IV.

Table IV. Effect of Variation in Temperature.

Pine-tar oil, 6 gm. Acid, 5 gm. Ore, 50 gm. Agitation in two 5-min. periods, skimming after each period. Analyses on 1-gm. samples.

Temp. °C.	Wt. of Froth, gm.	Wt. of Tails, gm.	Wt. of $BaSO_4$, gm.	Wt. of S in Tails from 100 gm.Ore	% S in Tails	% S Extracted.
25	20	36	0.850	12.0	92	8
40	29	27	0.535	7.3	57	43
50	22	34	0.640	8.8	69	31
65	14	42	0.450	6.2	48.6	57.4

Maximum extraction was obtained when the temperature of the solution was 50° to 65°. Although not evident in the tabulated results, the extraction of sulphides increases with rise of temperature of the solution. In observing the progress of experiments it was noted that the heated solutions acted in a much "cleaner" manner than those at room temperature.

5 *Effect of Size of Ore.*—To determine the proportions of the different sized particles present in the ore as a whole, and the amount of sulphide sulphur in the various sizes, a screen analysis was made. The results are given in Table V. Each lot of the sized particles obtained by screening was sampled and analyzed for sulphur. These results are also given in Table V, showing the distribution of the sulphur in the various sizes.

Table V. Screen Analysis of Bisbee Ore.

Screen Opening, In.	Mesh, approx.	Wt. per 100 gm. Ore.	Wt. of $BaSO_4$ from 1-gm. samples.	Equiv. S %.
0.0116	48	4.0	.....	....
0.0082	65	13.5	2.1038	28.9
0.0058	100	21.8	1.2003	17.04
0.0041	150	14.7	1.0022	14.05
0.0029	200	14.0	0.9175	12.60
Below 0.0029	200	32.0	0.7124	9.80

Table VI. Effect of Variation in Size of Ore.

Ore, 50 gm. Acid, 0.3%. Pine-tar oil, 6 gm. Temp., 65°C. Two 5-min. agitation periods. Analyses on 1-gm. samples.

Mesh	Wt. of Froth, gm.	Wt. of Tails, gm.	Wt. of $BaSO_4$	% S in Tails	% S Extracted
48- 65	12	44	1.1040	57.3	47.7
65-100	28	28	0.3396	27.3	72.7
100-150	26	30	0.1294	10.3	89.7
150-200	19	37	0.3490	38.0	62.0
Below 200	19	37	0.2500	35.0	65.0

It is seen that the method of crushing this ore to approximately 60-mesh was not very satisfactory, for a glance at the table shows a large amount of fines (below 200-mesh) to be present; while at the same time, a good percentage of coarse particles is in evidence. It is also evident that the coarser particles contain the greater percentage of sulphides; and as

it is subsequently proved in this experiment that the losses of metallic sulphides occur largely in those sizes over 65-mesh, this accounts for the low recoveries in the previous tests.

Separate tests were then made upon each of these sized lots, the results being recorded in Table VI.

The results show clearly that for satisfactory concentration by flotation, the ore should be properly sized. The above test indicates that for maximum extraction the ore should be crushed and sized between 100 and 150 mesh. This condition being very expensive to obtain in practice, a wider limit must be set; it is seen, however, that for favorable results all the ore should be finer than 65 mesh, and as uniformly sized as possible. A larger range of sizes does not apparently aid successful flotation in this case.

(It has generally been supposed that froth flotation processes are improved by the presence of a certain amount of sulphide slimes. At any rate, screen sizing, as conducted in this experiment, is out of the question for commercial applications of flotation processes, and an operator must content himself with crushing his ore to a sufficient degre of fineness to liberate the sulphides. What this degree should be is best determined by a screen analysis of the tailings from a test, rather than of the original ore.—Ed.)

Treatment of Coniagas Silver Ore.

The ore upon which the following tests were made was obtained from the Coniagas Mining Company, Cobalt, Ont., and represents the material fed to the stamps. The ore contains about 13 oz. Ag per ton, mainly in the form of pyrargyrite (Ag_3SbS_3), proustite (Ag_3AsS_3), argentite (Ag_2S), dyscrasite (Ag_2Sb), and native silver. The procedure was the same as for the Bisbee ore, but in this case the tailings were analyzed for silver.

The ore was first assayed, using three different charges, with results as follows:

	Charge No. 1		Charge No. 2		Charge No. 3	
Ore	1	A. T.	1	A. T.	1	A.T.
PbO	2¼	"	2	"	2¼	"
Na_2CO_3	1	"	1¼	"	1	"
Bx. Gl.	1/6	"	1/6	"	1/3	"
Bx. cover	1/3	"	1/3	"	Salt. cov.	
Ag. found, oz. per ton	13.61		13.62		13.10	

The chief difference between charges 1 and 2 is that the latter has somewhat higher Na_2CO_3, and is lower in PbO. Charge 3 is equivalent to 1 except that a salt is used. Charge No. 1 was selected for the assay of tails, as with this charge frothing was prevented and the slag was cleaner. Charge No. 2 gave equally good results, but the slag did not look so clean as that of No. 1.

1. *Variation of Oil.*—Preliminary tests were made to determine which oil is best suited for effecting flotation of the values in this ore. Results are given in Table VII.

Table VII. Effect of Various Oils on Cobalt Ore.

Ore, 100 gm. Water, 1500 c.c. Agitation, 1 min. Room temperature. Oil, 8 drops. Acid, 1 gm.

Oil	Wt. of Tails, gm.	Wt. of Froth, gm.	Oz. Ag per Ton Tails
Pine-tar	97	3.0	9.6
Fish	98.5	3.0	12.46
Sperm	98	2.0	12.94
Corn	84.0	16.0	13.36
Whale	98.0	2.0	13.8
Cylinder	(a)	....	.....
Rapeseed	90.0	10.0	10.87
Lard	90.0	10.0	13.13
Cottonseed	93.0	7.0	12.66

(a) No froth.

The results show clearly that pine-tar oil is far superior to the other oils tried. Rapeseed oil gave a comparatively good extraction, but it was noted that the froth was not so lasting as that produced by the pine-tar oil.

The amount of oil used in these tests was very small, the purpose being merely to indicate the most promising of the oils available, and at the same time to study their selective action. Here again it is seen that of the three or four oils giving the best results, pine-tar oil excels in selective action; whence this oil alone was used in the following tests.

The amount of oil was next varied from 1/3 gm. to 3.6 gm. per 100 gm. of ore. Results are given in Table VIII. This test shows that beyond 2.5 gm. of oil per 100 gm. of ore no benefits are derived from additional oil.

Several tests were then made to determine the effect of adding oil in successive portions. Under the same conditions as above, 2 gm. of oil (50 drops) were added in three parts,

Table VIII. Effect of Variation in Amount of Oil.

Ore, 100 gm. Water, 1500 c.c. Acid, 1.5 gm. Room temperature. Agitation period, 2 min. Pine-tar oil.

Oil, gm.	Wt. of Froth, gm.	Wt. of Tails, gm.	Ag in Tails, oz. per ton.	% Ag remaining in Tails.	% Ag Extracted.
0.3	7.0	93.5	11.44	84.0	16
0.6	12.0	89.0	10.20	75.0	25
1.0	15.0	84.5	8.25	60.6	39.4
1.3	11.5	90.0	8.28	60.8	39.2
1.6	15.0	87.0	8.68	63.8	36.2
2.3	16.0	87.5	6.66	49.0	51.0
3.0	25.0	78.0	.....	....	....
3.3	22.0	81.0	6.45	47.5	52.5

the first being 1 gm., and the second and third being ½ gm. each. The pulp was agitated each time for 2 min. and the froth was skimmed after agitation with each portion of oil. It was found that the weight of the froth obtained was far too great for good results. In other words, the froth contained nearly two-thirds the weight of the original ore.

A similar test was next tried, using half the amount of oil, namely ½ gm., ¼ gm. and ¼ gm. The weight of the froth obtained from 100 gm. of ore was 48 gm., while the metal contents of the froth was 48% of that contained in the ore, again showing that too much of the gangue was carried into the froth.

By using 100 gm. of ore and but ½ gm. of oil the extraction obtained from three 4-min. periods of agitation was 52.4%. In this test, the oil was all added at first and after 4 min. of agitation the froth was skimmed. The pulp was then agitated for two more 4-min. periods, without further addition of oil, and the froth was skimmed after each period. The weight of the froth, in this case, was 33 gm. When 1 gm. of oil was added in two equal parts, and the pulp agitated for 2 min. after each addition, the extraction obtained was but 51.6%.

Conclusions

It is to be borne in mind that every ore which can be successfully concentrated by flotation has its own set of best conditions. While those particular conditions mentioned below

refer primarily to the ore tested, the general principles are applicable to many if not all ores.

Bisbee Ore.—

1. Of the oils tried in these experiments, pine-tar oil appears to be the best frothing agent. Per unit of volume, it will collect in the froth more sulphides than the other oils which were tried. The oil used has a sp.gr. of 0.98 approximately.

2. The addition of acid is necessary, not only to increase the selective action of the oil, but at the same time to increase the extraction. It follows, then, that for a given weight of froth, that obtained when acid is used will afford the greater concentration of metals and metallic sulphides. The best results are obtained when concentrated sulphuric acid is present in quantities approximating 0.3% by weight of the water in the pulp.

3. With increased temperature, the extraction of sulphides from the ore is increased. The best condition is obtained at approximately 65°C.

4. Nothing shorter than 10-min. agitation periods gave efficient flotation, but this may be divided into two or more periods.

5. Sizing of the ore is necessary for best results. In these experiments, 100 to 150-mesh materials yielded the maximum extraction of sulphides, the greater losses occurring in those particles larger than 65 mesh.

6. These experiments indicate that successful concentration by flotation is possible with the Bisbee ore; but it is realized that commercial conditions are not the same as experimental. The results merely indicate the feasibility of the process and not the best actual working conditions. With improved machanical and metallurgical conditions, a higher extraction can undoubtedly be obtained.

A proposed plan would be to treat the whole ore, crushed through 65 mesh, by flotation. The frothed sulphides, after elimination of oil, would be roasted and smelted to matte. The SO_2 thus produced would be converted at once into H_2SO_4 and used for leaching the tailings from flotation, containing the oxidized portion of the ore. The advantages of such a process are:

1. No roasting of the ore necessary to convert the sulphides to soluble oxides, etc.
2. No obnoxious gases liberated.
3. Less time required than for roasting.
4. Less cost (based on general cost of flotation processes and on roasting).
5. Produce a high concentrate suitable for smelting in a copper matte furnace.

The chief disadvantages are:

1. Cost of mechanical agitation.
2. Cost of the oil.
3. Cost of fine crushing.

Coniagas Ore—

1. Pine-tar oil is the most efficient flotation agent among those oils tested.

2. Oil fractionation, and longer periods of agitation, gave as good an extraction with the consumption of less oil.

3. As this ore cannot be economically treated by cyanidation, it seems probable that, with proper regulation of working conditions, it can be concentrated so that the values may be recovered.

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GENERAL OBSERVATIONS ON STREET PAVEMENTS OF EUROPEAN CITIES

BY HENRY W. DURHAM.†

Up to the middle of the last century a pavement consisting of stone blocks laid directly on the ground surface of the street was considered satisfactory in all European cities. At the present time, such surface is used on a great part of the streets in every Europan city. It was not until 1890, when the placing of electric wires in underground conduits instead of on overhead poles was begun, followed within a few years by the introduction of motor-driven vehicles in large numbers, that the necessity for a rigid foundation under a repairable wearing surface for city streets assumed great importance.

Foundations.

At the present time, due to the great increase in weight of traffic on the streets of cities of the first class, and to the frequent necessity for opening them for the laying of various substructures required by conditions which have arisen within the past 25 years, there is universal agreement among those in control of city highways that concrete foundations are indispenable when constructing new pavements in important thoroughfares.

Such foundations are essential in almost all streets of American cities, which, in addition to having been disturbed for subsurface construction, are very largely on regraded ground; whereas many of the older cities of Europe have streets which have occupied their present position for hundreds of years. Subsurface conditions in London, on the other hand, due to the nature of the underlying material, are such as to justify the authorities there in demanding the heaviest foundations to be found anywhere, 12 in. being used in the central part of the city. But even in London there were

*Abstract of Chapter VII of a report on "Street Paving and Maintenance in European Cities," to the Mayor of the City of New York.

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In the summer of 1913 Mr. Durham was commissioned by the Mayor of New York City to attend the Third International Road Congress at London, and to take several months to study European pavements, which from time to time had been compared with New York City pavements, to the disadvantage of the latter.

found in the outlying residence districts a large proportion of satisfactorily surfaced streets without an artificial foundation.

Great differences exist as to the thickness of concrete foundation, where used, and the proportioning of materials composing it. Concrete 4 in. thick is regarded as satisfactory in many places, even in such an important city as Brussels. Probably the standard thickness at the present time is from 6 to 8 in. The proportions in which foundation concrete is mixed vary greatly. For purposes of comparison the following table shows some of the proportions used abroad:

Composition of Concrete for Street Foundations.

	Cement.	Fine Aggregate.	Coarse Aggregate.	Materials.
London:				
City and Westminster	1	..	6	Thames ballast, unscreened river gravel.
Lewisham	1	..	7	Thames ballast — unscreened river gravel.
Battersea	1	3 sand	5	Clean gravel.
Liverpool	1	6 crushed slag	3	Broken stone, 3-in. gage.
Paris	1	3¾ sand	7½	Stone or gravel.
Berlin and Charlottenburg	1	..	8	Fine gravel and sand.
Hamburg	1	..	7	Unscreened river gravel.
Vienna	1	3 sand	5	Gravel.

The work of concrete mixing is done almost entirely by hand, although concrete-mixing machinery has been introduced in Germany to a small extent. The subfoundation is generally rough graded, with about the same accuracy prevalent in New York City, but it is more usual to finish the concrete surface smooth.

The concrete is commonly laid between forms set transversely to the axis of the street at intervals of about 15 ft., materials being turned over on a mixing board between these forms directly into place. Final finish to the surface is then obtained by drawing a straight-edge across the width of the street, the concrete being mixed wet enough so that finer material flushes to the surface and produces a fairly smooth finish under the straight-edge. Where this method is not followed, the forms are placed longitudinally and the finished

surface obtained by drawing along on them a template formed to the proper transverse section.

Where wood pavement is to be laid, particular attention is given to obtaining an accurate, smooth surface, and a certain amount of hand-smoothing is sometimes employed. It was noted in London and in other cities, however, that by employing the method of accurately setting transverse strips to the surface grade on narrow widths of concrete, and then drawing a straight-edge or a screed along on these adjacent strips (between which the work of mixing and placing was carried on), that a sufficiently smooth finish was obtained with very little surfacing. For asphalt and granite pavement, it is not attempted to obtain such smooth results on the foundation surface; but usually a more accurate surface is obtained on all classes of work than in this country, though it is at the sacrifice of speed. The quality of the concrete is in no case superior to that being produced at the present time in New York City; and frequently it is inferior.

Stone Pavements.

Perhaps the most frequently used block in Europe is the squared block having generally cubical dimensions, of the type known in this country as "Belgian" block. The blocks are usually laid without foundation, but their regular shape permits of joints not exceeding 1 in. width and a surface much smoother under wheel traffic than that of the old-style cobble.

Another variation, but of the same class, is the type of large slab-block pavement employed in Italy and other of the more southern countries, composed of stones measuring from 18 to 24 in. on top, and having a 6-in. depth, laid with comparatively close-fitting joints. On a level street these pavements furnish fairly good foothold for horses, and still have a smooth surface under wheel traffic.

Variations from the cubical shape of the "Belgian" block were introduced in German and French cities, approximating more nearly to the dimensions of our granite paving block of today, but having the same general quality and wide joints as the old "Belgian" block.

A great part of the stone-paved streets in the continental cities (constituting generally a majority of the total area of carriageways) is paved with one or another of the above types

of block, either a granite or a material like trap, the latter called whin stone in Great Britain, and porphyry in France and Germany. The granite, being a softer material and subject to more and rapid wear, has not been so largely employed in the past, except on grades, where its lack of extreme hardness makes it less slippery for horses' feet.

With the introduction of concrete foundations under stone pavements, came a reduction in the depth of blocks, and today where this foundation is used in France and Germany, the blocks have a depth of from 5 to 6 in., instead of 8 in. or more, as when laid without foundation. In the German cities, two standard types of specifications are recognized for these two classes of pavement, and where concrete foundation is employed stones of smaller surface area and more closely dressed are used.

As characteristic of the extent to which concrete foundation is employed under stone pavements on the continent, reference may be made to the city of Paris, where only one-eleventh of the entire area of stone-block streets is so constructed. Liverpool has tried a great number of different types of block, both with and without concrete foundation, although for the past 25 years concrete foundations have been almost always used. The fact that certain peculiarly shaped blocks are giving satisfaction in the streets of Liverpool does not indicate that this type of block is a standard nor one to be recommended for employment at the present time, because much difficulty is now experienced in obtaining any but the standard set from the Welsh and Scotch quarries which supply the English cities.

The best foreign practice is to lay stone pavement on a concrete foundation, as in this country, employing a cushion of sand or fine stone screening of 1 to 2 in. thickness, sometimes mixing in a small proportion of cement, in order to have subsequent rigidity in the cushion.

Joints are sometimes filled with gravel or fine crushed stone and then poured with tar or with a mixture of tar and sand; or, as the practice is in some cities, with a liquid cement grout. A combination of the two methods, using a mortar filled joint for half the depth with tar at the top, is sometimes used. For the large areas of stone pavements with no foundation,

a great proportion has no filler in the joints other than fine gravel or sand. On account of the lower rate of wages paid in Europe, it is possible to produce blocks more accurately dressed for the same amount of money than can be done in this country. Usually, a small amount of tool work can be done on the sides in order to permit the block to be laid with closer joints, but only in isolated instances where specially dressed blocks are employed are the joints less than ½ in. width.

Nowhere do any road authorities recommend small cube-block pavement (that is, blocks 2 in., 3 in., and 4 in. on the side) as a competitor or substitute for the large granite-block type of pavement on a concrete foundation. Where laid in England, the small cubes are used as an alternative to some type of bituminous concrete.

The small-cube pavement streets and roads in Germany are almost always a means of substituting a harder surface for ordinary water-bound macadam. The blocks are frequently laid with sanded joints as a carpet coat on the old macadam; and when laid on a concrete foundation with tar-filled joints, they are still employed only on streets of light traffic where bituminous concrete or a sheet-asphalt surface would otherwise be used.

The engineers in Birmingham and the Borough of Chelsea have found the small-cube pavement satisfactory; the engineer of Battersea does not think it adaptable for employment on a city street. The experimental lengths laid on the Sidcup Road running out of London, where the small cubes have been used in competition with various other types, are too new to allow the drawing of definite conclusions, but appear to have been satisfactory up to the present time. The Liverpool engineers do not consider the small-cube pavement suitable on any class of city street; and they regard the rectangular granite block as best for heavy traffic and the bituminous macadam the best for the light-traffic residence streets.

The advantages of the small-cube pavement for suburban roads are: Low cot of maintenance, and absence from dust when constructed with tar-filled points. The disadvantages appear to lie in its noisiness, the tendency of the blocks to wear round, due to wide joints, and their liability to become displaced and crushed on account of their small size. Cases

were observed where this type of road surface showed material wear both under high-speed pleasure automobile traffic and slow-moving steel-tired motor and horse-drawn heavy traffic.

There are a few instances abroad of small areas laid with specially dressed granite block at a cost much in excess of anything we have, and presenting a surface almost as smooth as asphalt. But even could such a pavement be laid economically in this country, it is doutbful whether it would be advisable, on account of its having a surface too smooth and slippery.

Wood Pavements

There are two classes, soft pine and hardwood. The blocks have dimensions approximating those used in this country—a depth of from 3 to 5 in., a width of 3 to 4 in., and a length averaging between 6 and 10 in.

Australian hardwood has been very extensively laid, both in England and on the Continent. Wherever it has to carry heavy traffic it has proved unsatisfactory. The blocks have a tendency to wear round and become rough and uneven. Some attempts have been made to take up the blocks from streets where this has occurred, plane off about ½ in. from the heads and relay them. This has been done with some success in various cities, but it is at best a temporary expedient, and in no city of first importance is it regarded as desirable to lay hardwood blocks at the present time. The blocks are always laid directly on a smooth concrete surface, being previously hand-dipped in tar, and the surface is poured with the same material. Soft-wood blocks, made of Norwegian, Swedish and French pine and similar material, somewhat softer than our long-leaf yellow pine but very much resembling it in appearance, are being used with great success at the present time.

In the construction of soft wood-block pavement,, the concrete foundation is finished with a perfectly smooth surface to the proper crown of the street and the blocks, previously treated with from 4 to 12 lb. of creosote oil per cu. ft., are laid directly on this surface. After the blocks are laid in place, and this is usually done with the joints a trifle less close than in the American practice, the surface is swept with

tar, which has been hand poured, as a joint filler. When this has sufficiently hardened, the entire surface is gone over with a thin coating of liquid cement grout, presumably to reduce the amount of stickiness from the tar, and the street is finally spread with a layer of granite screenings or crushed gravel, which traffic soon rolls into a soft surface of the wood. This produces a gritty nonslippery surface, which permits this type of material to be laid on gradues up to 5% with entire success, under horse-drawn traffic. When well done, a wood pavement presents undoubtedly the finest street surface in existence; when the contrary is the case, they are about as poor as any to be found.

Asphalt

The asphalt pavements of European cities are largely constructed from the natural asphalt rock found in various parts of Italy and southern France. It consists of a limestone impregnated with bitumen, which is mined in rough fragments, and run through a crusher and mill, and, after being reduced to a fine powder, is heated to a high temperature, producing a material similar in consistency to the artificial asphalt topping used in this country; but it is of a brown color. The heated material is taken to the streets in wagons, spread to a depth sufficient to give a final thickness of from 1½ to 2 in. on the concrete foundation, and, after a preliminary rolling with a hand roller, is given its final compression by hand-ramming. Where the rock contains a deficiency in the amount of bitumen necessary, the required addition is made.

The City of Paris prohibits the use of any of the old wearing surface removed from the street, but on new pavements in Berlin and Charlottenburg the contractor is permitted to employ this old material in the proportion of about one-third of the total quantity. The practice is to take the old wearing surface as it is brought in carts to the plants, mixing it in alternate layers with the broken rock from the mines, the mixture then being run through the crusher.

Rock-asphalt pavement has been employed for a long time in the principal European cities, producing a surface very similar to asphalt pavements of American cities, but somewhat harder and possibly a trifle more slippery under cold-weather conditions. In extreme warm weather it is liable

to the same tendency encountered in this country to soften and roll. It is successfully employed in London, Paris, and Berlin, on streets that would not be regarded as suitable for our type of asphalt. It is nowhere regarded as satisfactory on any grade.

Abroad, asphalt pavement is usually thought to be too high priced to employ in quiet light-traffic residence streets to the extent followed in New York City. All new districts in Berlin, however, are being developed by asphalt roadways, and Paris has made contracts for the repaving with asphalt of a large extent of the existing wood, stone block and macadam. Vienna is now undertaking an extensive repaving of its old stone-block streets mainly with asphalt.

There have been some attempts to introduce American asphalts in competition with the European. The Thames Embankment has a Trinidad asphalt surface on the old macadam foundation, which has given satisfaction. A few experimental lengths of American asphalt have been laid in Berlin, and a company now operating there is preparing to make contracts for the use of some of the asphalt from this country. In general, however, the foreign engineers are satisfied with their own type of material and are somewhat averse to trying experiments with another.

The point must be emphasized that many of the superior features in regard to foreign asphalt streets, as they strike the observer's eye, are directly attributable to the much better and more thorough street-cleaning system in operation; while the points of criticism based on the condition of certain American asphalt streets can also be attributed in many cases to the faulty foundation conditions, which have not prevailed abroad.

Summary.

These three types of surface—rectangular stone block, wood block, and compressed rock asphalt—are the prevalent surfaces for modern city street construction in the great cities of Europe. A great variety of other types can be found in small amounts and generally where traffic is light. These include various kinds of compressed asphalt block, usually a thin slab or plate laid on concrete foundation; concrete blocks cast in forms under pressure, usually large slabs and laid more

often for sidewalks than for other purposes; slag blocks, which present a smooth surface when new but rapidly deteriorate even under light traffic conditions; and brick, both ordinary hard burned and vitrified. Hard-burned bricks dipped in tar have been used in Brussels on some of the parkways, and there are many miles of brick roads in Holland.

All classes of tar and bituminous macadam made under many processes, some of them patented and with various names, are being tried out and extensively used for suburban and country road traffic, as in the United States. Tar macadam particularly is being largely introduced in the residence districts of European cities, under conditions similar to those where sheet asphalt on concrete is so often employed in the Borough of Manhattan, New York City.

After classifying all improved and modern pavements, it is found they are much in the minority as compared with those which may be termed ordinary or usual—large stone blocks on sand, or water-bound macadam.

CHEMICAL ABSTRACTS.

BY ELWYN WALLER.

Apparatus—Manipulation.

Barium Sulfate. Osborne (C.N., CVIII, 204).—Krak's method of managing a filtration with suction is to precipitate hot, and after settling to pour the supernatant solution through the filter. Then stir the ppt. well with 10cc. conc. $NH_4C_2H_3O_2$ solution slightly acid. The $BaSO_4$ is almost immediately converted to a crystalline form, and filters perfectly clear. The author has experimented to find what the action may be. Adding the acetate to the solution while it still contains more or less HCl or NH_4Cl failed to produce the effect. Precipitation in the cold, and treatment as above described, were ineffective unless the ppt. was boiled with the acetate for some time. The conclusion is that $BaSO_4$ is dissolved by the acetate, to an extent permitting rearrangement of the molecules in crystalline form. When precipitated hot the crystals are nearly large enough for clean filtration, and they quickly grow to the required size. In a cold precipitation, long heating is necessary to produce the same result.

Substitute for Platinum in electrolytic analysis. Calhane and Wheaton (Met. Chem. Eng., XII, 87).—Fine brass gauze is proposed (100 mesh.). After washing with caustic alkali to remove greasiness and rinsing off, the gauze, made up into suitable form, is lightly plated with Cu, before washing, rinsing with alcohol, and weighing. The cost is 20 to 30c. per electrode. Mechanical stirring gives but little advantage. The brass gauze could not be used in KCN solutions.

Non-ferrous Ores and Metallurgical Products.

Rapid Analysis of Bronze and Brass. Trickey and Fegely. (J. Ind. Eng. Chem., VI, 556).—For lead. Diss. 0.5 gm. in 12 c.c. H_2O containing 4 gm. tartaric, adding 4 c.c. conc. HNO_3 with heat. Cool slightly, add 10 cc. conc. H_2SO_4, and heat to expulsion of N fumes—no more, lest the tartaric carbonize. Dilute with 100 c.c. H_2O, adding 75 c.c. alcohol, let stand a few minutes, filter, off $PbSO_4$, wash with dil. H_2SO_4, then with alcohol. $PbSO_4 \times 0.683 = Pb$.

For copper. Diss. 0.5 gm. in 5 to 10 c.c. HNO_3, keeping covered until violent action ceases. Evaporate to syrup. Add KOH until slight permanent ppt. of $Cu(OH)_2$, then enough acetic to dissolve, and a little more; cool, add 40 c.c of 10% KI. Add 5 c.c. starch sol. and titrate with standard $Na_2S_2O_3$. Interference by Fe, if present, is prevented by adding NH_4F. If As_2O_3 or Sb_2O_3 are present, they must be oxidized up by boiling with Br. Boil out all Br. before cooling and proceeding.

stant weight. The precise composition of the salts obtained was not determined, but the weight × 0.0151 gives that of the P present. Precipitation in presence of such amounts of SiO_2 as would be possibly present in irons and steels gave results slightly high.

Chromium in manufactured Irons, etc. Walters. (Met. and Chem. Eng., XII, 310).—The method is that of Phillips. Diss. 2 gm. in 60 c.c. dil. H_2SO_4 (1:5) add 6 c.c. HNO_3 (Gr. 1.2) and boil a few minutes. Filter and wash 4 or 5 times, bringing sol. to about 125 c.c. Add 50 c.c. $AgNO_3$ sol. (4 gm. per litre) and about 5 gm. $(NH_4)_2S_2O_7$; heat to boiling. If permanganate is not formed, add more persulfate, and boil again. Boil to destroy excess of persulfate, then add 2 c.c. HCl and boil to destroy $HMnO_4$, and expel Cl. Cool, dilute to 400 c.c., add measured excess of standard $Fe(NH_4)_2(SO_4)_2$ sol. and titrate back with standard $KMnO_4$.

Tin ores and concentrates. Hutchin (Inst. Min. and Met., Bull. 113).—The finely pulverized ore is intimately mixed with approx. an equal weight of powdered CaO, which may be used somewhat in excess, and charged into a crucible of alundum or of porcelain. The crucible is set in a hole made to receive it, in a thick asbestos board. Cover the crucible, and apply the heat of a Teclu or large Bunsen burner for 15 or 20 min. Cool, brush out the charge, diss. in HCl, reduce with Ni, and titrate with I sol.

Wraight and Teed have investigated the Pearce-Low method—fusion with Na_2O_2 in Fe or Ni crucible, diss. in HCl, reducing with Ni, and titrating with I sol.—and sum up the conditions necessary for success. The use of Ni crucibles. and reduction by Ni are particularly prescribed. Ti, W and Bi are interfering elements. For other points reference to the original article is advisable. (cf. Met. and Chem. Eng., XII, 350).

Silver—Rapid determination in mill solutions. Clevenger Eng. and Min. J., XCV, 892).—Put about 5 gm. Zn dust in the bottom of a Gooch crucible, so as to make a layer about ⅛ in. thick. Pour through this a measured amount of the sol., keeping the Zn always covered with sol. Rinse the Zn into a beaker, diss. by adding slowly 15 c.c. HNO_3, boil out nitrous fumes, dilute according to requirements, and titrate with standard NH_4CNS. Hg, and metals forming colored solutions, as Ni or Co should be absent. Cu may be present up to an amount equal to that of the Ag.

Iron—Steel—Ferro-alloys.

Phosphorus in Vanadium Steels. Cain and Tucker (J. Ind. Eng. Chem., V, 647).—When V is in pentad condition, the MoO_3 separation of P_2O_5 is partially prevented, or there may be some co-precipitation. When V is tetrad, no such interfer-

ence occurs. $FeSO_4$ will convert it to that form, but if the temp. is high enough to allow interaction of $FeSO_4$ and HNO_3, lower N oxides will cause reoxidation of the V and the determination is spoiled. The method recommended is: Diss. 1 to 2 gm. of the steel in 100 c.c. HNO_3 (1.135), oxidize by slight excess $KMnO_4$, destroy excess $KMnO_4$ by SO_2. Cool, add 40 c.c NH_4OH (0.96). Cool sol. to 15° or 20°C., add 5 c.c. sat. sol. $FeSO_4$ and a few drops of conc. sol. SO_2. Then add 40 c.c. MoO_3 reagent and shake well for 10 min. Let settle, filter, etc., proceeding subsequently in the ordinary manner.

Cobalt in Steel. Slawik (Chem. Ztg., XXXVIII, 514).—Diss. 2 to 4 gm. in HCl and $KClO_3$ and boil out excess of acid. Add excess ZnO to sol. in a 500-c.c. flask. Shake vigorously and dil. to the mark. All Co remains in solution. Filter off 250 c.c., to which add HCl and evap. to 100 c.c. Add 20 c.c. conc. HCl and precipitate Co with 2% sol. of nitroso beta naphthol. Stand in a warm place until solution clears, then filter and ignite to Co_3O_4 for weighing.

Separation of Titanium from Iron. Thornton (Am. J. Sci., XXXVII, 173).—The sol. should receive the addition of three times as much tartaric as the combined weights of Fe_2O_3 and TiO_2 present. Neutralize with NH_4OH, then add 1 or 2 c.c. H_2SO_4 (1:1) and pass H_2S to complete reduction of the Fe. Then render ammoniacal, and pass more H_2S, until all Fe is precipitated. Filter, and wash with very colorless dil. $(NH_4)_2S$. Acidify the filtrate with H_2SO_4, and boil out H_2S. Neutralize so as to leave an acidity equivalent to 2.5 c.c. H_2SO_4 (1.1) per 100 c.c. Cool, and add solution of "cupferron" (about 6% strength). Wash with cold H_2O. Dry and heat carefully until volatile products are expelled, then ignite more strongly to burn out C.

Rarer Metals.

Thorium in Monazite Sand. Carney and Campbell. (J. Am. Chem. Soc., XXXVI, 1134).—The methods heretofore used have been: (1) by $Na_2S_2O_3$. (2) by H_2O_2. (3) by fumaric acid. (4) by nitrobenzoic acid. To these the authors add another—by $Na_2P_2O_7$. The method is: Treat 50 gm. of the sand with 100 c.c. conc. H_2SO_4 in Fe dish covered with a watch glass, at 250° for 5 to 8 hr. until decomposed. Excess of H_2SO_4 is not expelled. Cool and add slowly to 400 c.c. cold H_2O in a vessel surrounded by ice water. Stir and let stand until sulfates are all dissolved. Filter and dilute with the washings to 1 litre. Of this take 50 c.c. (=2.5 gm.) add 5 c.c. HCl (Gr. 1.19) and dilute to 450 c.c. Stir and add slowly 15 c.c. $Na_2P_2O_7$ sol. (25 gm. in 500 c.c.) Heat to boiling, stirring when near the boiling point. Boil gently 5 min. Let stand 5 to 10 min. Filter, washing with H_2O acidified with HCl. Put filter and all into a Kjeldahl flask, add 15 c.c. conc. H_2SO_4, and

a little NH_4ClO_4. Heat until a brown liquid results, then add more NH_4ClO_4, and heat to complete oxidation. (Solu. should be slightly yellow). Place the flask in cold H_2O, and add about 100 c.c. H_2O, with stirring to dissolve the sulfate. Rinse with a sol. of 30 gm. NaOH in 125 c.c. H_2O, stir and heat, then filter on a hardened paper. Put the filter back into the beaker, pour over it 10 c.c. HCl (Gr. 1.19) let stand a few minutes, then dilute with 150 c.c. H_2O and boil. Filter from the paper, dilute to 400 c.c., add 3 c.c. sat. sol. of SO_2, heat to boiling, and reprecipitate with $Na_2P_2O_7$ as at first. Convert to sulfate and hydroxide as before. Finally dissolve hydroxide in 5 c.c. conc. HCl, dilute, boil, filter off the paper, and precipitate by sol. of 2 gm. $H_2C_2O_4$. Dilute to 450 c.c. Let stand, warm over night, filter, wash with H_2O faintly acid with HCl, ignite to ThO_2 and weigh. Precipitate contains no phosphate.

BOOK REVIEWS.

"Introduction to Organic Chemistry." By John Tappan Stoddard. Cloth; 4½x7 in.; x + 419 pp. P. Blakiston's Sons & Co., Philadelphia, 1914. Price, $1.50.

"This book is intended to be used in connection with lectures, recitations, and laboratory work in the first course of Organic Chemistry in college. The author has endeavored to present the subject simply, directly, and connectedly, so that the student may gain a clear idea of the principles of organic chemistry and its relations to general chemistry."

The author has kept close to this aim as outlined in the preface. The general properties and methods of formation of compounds are consistently given under all classes in semi-tabular form and these are supplemented with numerous examples and excellent tables which are very helpful. The book is replete with good structural formulas. The Geneva or official system of nomenclature is given in addition to the older and more common names. There are many cross-references but more could well be added. Some of the newer ideas and methods are also included. The Grignard reaction, however, although its applications are given in the early portion of the book (pp. 36-7), is not mentioned further in the different summaries except under aromatic hydrocarbons (p. 274) and acids (p. 354). The hybrid terms, "monovalent, divalent," etc., are used throughout instead of the preferable "univalent, bivalent."

Since it is the duty of the reviewer to point out any incorrect statements or misleading typographical errors, attention is drawn to the following: The use of the term "nascent hydrogen", pp. 26, 35, etc., as a reducing agent, and oxygen as an oxidizing agent, as in "the first action of the oxygen is to form an additional hydroxyl group," p. 112, line 19, is questionable in the light of modern theories of reduction and oxidation. On p. 49 mention should be made that only those actetylenes with the "triple bond" between two carbon atoms at the end of a chain react with an ammoniacal solution of cuprous chloride to form acetylides. On p. 38, line 4, "propyl" should read "pentyl;" p. 49, line 2, "calories" should be written with a capital in accordance with common usage since large Calories are meant, as explained on p. 51; p. 54, line 23, "propylene chloride" should read "chlorpropylene;" p. 135, last line, the second part of the parentheses and the subnumeral 3 in the formula for triethylamine should precede the N; p. 205, l. 25, "ducitol" should read "dulcitol;" p. 261, l. 9, "49° 48′" should read "49° 28′"; p. 315, l. 22, "oxidized" should read "reduced;" p. 321, l. 10, the formula for azoxy benzene should have only one bond between the two N's; p. 358, l. 24, the chemical name of saccharin is usually given as "o-sulpho-

benzoic-acid-inide" instead of "imide;" p. 363, l. 22, "chlorhydrin" should read "cyanhydrin;" p. 380, l. 1, "borneol" should read "isoborneol;" p. 383, an H in the naphthalene formula is misplaced; and p. 405, l. 4, the "not" should probably be omitted.

Harry L. Fisher.

Handbook of Construction Plant. By Richard T. Dana. Limp leather; 4½x7 in.; 702 pp.; 312 illus. M. C. Clark Pub. Co., Chicago. 1914. Price $5.

This is an alphabetically arranged compedium of that sort of information which, while practically indispensible to those engaged in engineering enterprises, is often difficult to obtain. It includes not only manufacturer's prices for equipment of all kinds, but also presents typical working costs from reliable sources. Discussions and comparisons are omitted, for want of space, and attention is directed exclusively to practical details. For use of students engaged in preparation of engineering projects we consider this book to be fully as valuable as Gillette's cost handbooks. E. K. J.

Methods in Metallurgical Analysis. By Charles H. White, Assistant Professor of Mining and Metallurgy in Harvard University and in the Massachusetts Institute of Technology. Cloth; 7½x5 in. ix + 356 pp.; 105 illustrations and numerous tables. D. VanNostrand Company, New York. 1915. Price, $2.50.

The book is a compilation of methods which are used in American metallurgical laboratories. The methods are given concisely, and in such cases as the author thought necessary for clearness he has given explanatory notes and back references, which features will be appreciated by the novice. Footnote referneces are given so as to enable consulting of the original articles.

The book was especially prepared to meet the needs of students, and beginners who have not had much experience in analytical work. For the benefit of these, the first 45 pages are given to a concise description of the equipment of a laboratory, the sampling of ores, and a more detailed explanation of the usual operations in both gravimetric and volumetric analyses. The operating chemist will, however, find the book an excellent guide in his work, as the methods of analyses which are given have been selected with regard to accuracy and rapidity of execution.

The book is an excellent handbook for the commercial analyst as well as for the student. Features which will be appreciated are the chemical equations which indicate the principal reactions upon which the analyses are based; also a list of the reagents and solutions required for the methods is given, and their preparation is described.

The determinations of the commoner constituents of ores are given on pages 45 to 103. Analyses of iron, steels, alloy steels, iron slags, and limestone are described on pages 103 to 168.

Pages 168 to 223 are given to methods of analyses of ores and products of the metallurgy of copper and lead, brasses, bronzes, and alloys containing copper, zinc, lead, antimony, phosphorus, bismuth, nickel, and cobalt. The methods given include the electrolytic, gravimetric, and volumetric methods for copper, and volumetric and gravimetric methods for lead, zinc, arsenic, antimony, manganese, iron, silica, sulphur, aluminum, selenium, tellurium, phosphorus, bismuth, nickel, and cobalt. The determination of gold and silver in copper bullion is described. The fire assay of gold and silver in ores, in copper and lead bullion, and in cyanide solutions, the testing of cyanide solutions and commercial cyanide, and the determination of platinum and palladium are described on pages 223 to 252.

The analyses of coals, petroleums, and gas, and the determination of their calorific value are outlined on pages 253 to 285. The analyses of clays is outlined on pages 286 to 289. Methods for the determination of some of the minor metals (chromium, nickel, cobalt, cadium, mercury, tin, tungsten, vanadium, uranium, lithium, strontium, barium, columbium, tantalum, caesium, germanium, glucium, thallium, cerium, thorium, yttrium, and zirconium) are given concisely on pages 290 to 306. Back reference enables the methods to be given in condensed form. References to the original articles are given. A chapter, pages 307 to 313, on the analysis and testing of lubricating oils and boiler water contains the methods which are in general use in the works. Pages 314 to 323 contain qualitative methods for the detection of the metals.

E. F. Kern.

Structural Engineering. By J. E. Kirkham, Prof. of Structural Engineering, Iowa State College. Cloth; 6x9 in.; 669 pp.; 452 figs. and tables. Myron C. Clark Publishing Co., New York. 1914. Price, $5.

The title of this book is misleading; in fact the opening paragraph, in which the author defines structural engineering as "that part of civil engineering pertaining to the designing of steel structures" is in error. Structural engineering embraces not only steel structures but those of wood, masonry, concrete, etc., as well. This volume deals only with structural steel design and such incidentals as floors, and roofs.

So many books have appeared on this subject, and so many have been simply rearrangements of old and well known material, with perhaps a new system of notation to vary the monotony and confuse the student, that there would seem to be

little room for another volume that offers so little new except in the matter of arrangement. The author is doubtless justified in preparing his own text to suit his own class-room needs, but the practicing engineer, who already has a good text on this subject, will not increase his library if by so doing he adds no new ideas or data.

The book is well written. It covers the subject in a clear and thorough manner and in addition to the usual chapters on graphic statics, influence lines, and details of steel design, also contains in the first 123 pages a very clear and concise statement of the principles of the mechanics of materials. This feature will doubtless appeal to a practicing engineer who can thus obtain a clear statement of both these subjects in one volume. It also contains some excellent exercises for drawing-room work and a brief chapter on "structural drafting," which, incidentally, does not mention any other drafting than that connected with steel detailing.

It is thus seen that this work combines in one volume that portion of structural drafting, mechanics and structural design that has to do with steel structures, and while this combination may have its advantages we cannot but feel that it is a step in the wrong direction so far as student use is concerned. The increase in "simplification and efficiency" that has been claimed by many writers, who have gone over the subject of mechanics and picked out only those portions that find immediate practical application and have given their students this form of predigested data, has resulted in filling the profession with a large number of narrow minded, "half-baked" engineers who may make good draftsmen and detailers but have not got that firm grasp of fundamentals necessary if they hope to rise higher than this. It is a step toward bringing the university down to a level with the correspondence school, a result that seems to be desired by some of our universities, many of our engineers, and almost all students, and is furthered by many instructors, who find that students like this kind of instruction because it is easy for them; incidentally it is also easy for the instructor. An engineer requires more hard work to educate than a draftsman, and students generally fail to appreciate the difference between the two. We do not intend to intimate that the author has any "high spot" method of instruction in mind in offering this volume, but it is a step in that direction, and a step that is easy to take and is frequently taken before it is realized.

The book also contains a large amount of numerical work and details that will doubtless be welcomed by many, but in our opinion renders it dangerous as a text. Details are important and necessary, but too great attention to details frequently results in losing a firm grasp of the general principles

and fundamental facts, and the development of a microscopic field of vision and thought. J. K. F.

Source, Chemistry, and Use of Food Products. By E. H. S. Bailey, Ph.D., Prof. of Chemistry, University of Kansas. Cloth; 5½x7¾ in.; 517 pp.; 75 illustrations. P. Blackiston's Son & Co., Philadelphia. 1914. Price $1.60.

While not intended primarily for engineers, this book is absorbingly interesting to that large and steadily growing class of people who take an interest in their "vittles." Of the three-corned field designated by the title, that part devoted to chemistry is decidedly subordinated to the others; chemistry is nowhere developed beyond the understanding of an ordinarily intelligent person. Those paragraphs which describe the sources of foods and compare their relative merits are particularly interesting; so also are those which describe briefly the methods of preserving, marketing, and manufacturing the various products, many of which are unknown on American tables. We have found it a most fertile source of interesting information, and more readable than some works of fiction.

E. K. J.

Street Paving and Maintenance in European Cities. By H. W. Durham, formerly Chief Engineer of the Bureau of Highways, Borough of Manhattan, New York. Cloth; 7x10 in.; 446 pp.; 280 photographs, and numerous maps and tables. Published by the office of the Borough President of Manhattan. 1915.

Mr. Durham's comprehensive report pertaining to the organization of highway departments, and methods of construction and maintenance of pavements in 40 of the principal cities of Great Britain, France, Germany, Belgium, Holland, Austria, Switzerland, and Italy, will repay careful study by highway engineers of the United States. The author has included in the Appendix extracts from reports and complete specifications covering construction of many of the types of pavements used in European cities. These specifications, all of which have been translated into English, will prove of interest and considerable value to American engineers. The report is profusely illustrated with cuts which pictorially record highway engineering practice in the several European cities visited by Mr. Durham during his three months' inspection tour. Every progressive highway engineer should secure a copy of Mr. Durham's admirable report, as a thorough knowledge of methods used and results secured under various conditions materially aids in the determination of the most efficient an deconomical methods to adopt under local conditions. Chapter 7 of the report, summarizing the different methods of surfacing streets, is reprinted on an earlier page of this issue. A. F. Blanchard.

ALUMNI NOTES.

1871 and 1883. Pierre de Peyster Ricketts, E. M., and John H. Banks, E. M., have announced that their partnership in mining and metallurgical testing has been dissolved by mutual consent. Both will open new offices—Mr. Ricketts at 80 Maiden Lane, Mr. Banks at 61 Broadway.

1873. The honorary degree of Doctor of Science was conferred by Rutgers College on Frederick A. Canfield, E.M., at the last Commencement.

1877. Arthur Thacher, E.M., western manager of the New Jersey Zinc Co., visited New York in April, 1915, on business of the firm.

1879. Thomas H. Leggett, E.M., has opened a new office at 149 Broadway, where he will continue the practice of mining engineering.

1880. H. A. Wheeler, E.M., has been elected chairman of the St. Louis section of the American Institute of Mining Engineers.

1883. Walter Harvey Weed, E.M., has moved from Houghton, Mich., to New York City, where in addition to his professional work he will supervise the annual publication of The Copper Handbook.

1885. Ira H. Woolson, E.M., is the author of an elaborate illustrated report on the fire that occurred at the Edison Phonograph Works on Dec. 9, 1914, dealing with the behavior of the different types of structure under intense heat. The report was issued jointly by the National Fire Protection Association, and the National Board of Fire Underwriters.

1887. W. H. Aldridge, E.M., visited northern Mexico in May, 1915, on a tour of inspection of mining properties for which he is responsible.

1887. George S. Rice. E.M., chief mining engineer of the United States Bureau of Mines, at the Pittsburgh Experiment Station, has been appointed on the international jury of awards of the Panama-Pacific Exposition, for the mining department, and will be in San Francisco for that purpose May 10-20.

1887. R. E. Slade, Ph.B., has been appointed engineer of the Providence Gas Company, Providence, Rhode Island.

1887. Frank McMillan Stanton, E.M., is treasurer of the Mohawk Mining Co., treasurer of the Wolverine Copper Mining Co. and vice-president of the Michigan Copper Co., all of Michigan, and president and general manager of the Fort Mountain Talc Co. of Chatsworth, Ga.

1891. J. S. Langthorn has been elected president of the Brooklyn Engineers' Club for 1915.

1895. Henry W. Durham, C.E., on Feb. 1, 1915, resigned his position as chief engineer of the Bureau of Highways,

Borough of Manhattan, to which he was appointed three years ago. He recently made a tour of European cities to study paving methods and his report has been published by the City of New York. A review of the book, and a reproduction of one of its most interesting chapters will be found on preceding pages of this issue.

1896. Charles S. Witherill, Met.E., formerly superintendent of the copper department of the Balbach Smelting and Refining Co., Newark, sailed on January 9 for Chuquicamata, Chile, as general superintendent of the reduction plant of the Chile Exploration Company.

1897. W. W. Schlecht, C.E., is in charge of the United States Reclamation Service irrigation project on the Milk River, Montana, which is to provide for the irrigation of about 200,000 acres of land.

1898. Orleans Longacre, Jr., has developed a profitable zinc mine near Joplin, Mo., from whic ha number of Columbia men are drawing dividends.

1900. J. A. Fulton, E.M., superintendent of the Melones Mining Co., Melones, Cal., was married Aug. 19, 1915, to Miss Anita Bertheau, of San Francisco.

1900. Benjamin Magnus, E.E., who has been general manager of the Mt. Morgan Gold Mining Co., of Queensland, for several years, has resigned that position and also that of consulting engineer to the Electrolytic Refining Co., of Port Kembla. He intends to leave Australia in June, returning to San Francisco after a trip through eastern Asia.

1901. D. M. Myers, Mech.E., is the author of a book "Preventing Losses in Factory Power Plants" recently published by the Engineering Magazine Co., New York. He has recently formed a partnership with John S. Griggs, with offices at 110 W. 40th St., New York.

1902. F. C. Merry, E.M., for several years manager of the Ferguson mines, B. C., resigned his position and returned to New York in March, 1915.

1902. Walter Percy Hatch, Mech.E., is with the Morgan Spring Co., Worcester, Mass. On Feb. 20, 1915, he married Miss Jessie May Thomson, of Lansdowne, Pa. Address: 383 Chandler St., Worcester.

1902. The firm of Thompson Towle & Co., brokers, will be dissolved on April 30, and David W. Smyth, E.M., the floor member of the firm, will enter the new firm of Filor, Bullard & Smyth, with offices at 61 Broadway, New York.

1902. Horace F. Lunt, E.M., has been elected second vice-president of the Colorado Metal Mining Association, an organization to unify the mining interests of the state and to promote mining therein. His office is in the Gazette Building, Colorado Springs, Col.

1902. Frederick B. Irvine, E.M., is with the Morgan Engineering Co., at Dayton, Ohio.

1902. H. F. Haviland, E.E., is vice-president and western manager of Walker Brothers & Haviland, of New York, Philadelphia, and Chicago. They have recently been appointed general sales agents for the Industrial Controller Co. of Milwaukee. Haviland's office is in the Monadnock Block, Chicago.

1903. Gelasio Caetani, E.M., consulting engineer, of San Francisco, is now in Rome, having received a commission on the engineering staff of the aeronautic corps of the Italian army.

1903. John F. Bauchelle, E.M., mill superintendent of the Bingham-New Haven mine, Bingham, Utah, visited New York with Mrs. Bauchelle in April, 1915.

1908. Francis W. Collins, E.M., has completed an engagement of several months duration for the Chesapeake and Potomac Telephone Co. of Baltimore. He was retained as consultant on special studies connected with some phases of the valuation of that company's properties in the state of Maryland.

1905. Sidney Rolle, E.M., is cashier of the United States Metals Refining Company's plant at Chrome, N. J. He was married on December 2, 1914, to Miss Maude Catherine Williams, of Hancock, Mich.

1906. Herbert C. Enos, E.M., engineer for the American Smelting and Refining Company's mines in Mexico, was married on Feb. 16, 1915, to Miss Caroline Nolan, in Salt Lake City. Address: Hotel Paso del Norte, El Paso, Texas.

1906. Mortimer Freund, E. E., is a member of the firm of Eadie, Freund & Campbell, consulting engineers, with offices at 7 W. 45th St., New York.

1907. Richard M. Taylor, C.E., was married June 5, 1914, to Miss Ruth Campbell of Newark, N. J. Taylor is with the Lawyers' Title Insurance and Trust Co., 160 Broadway, New York.

1907. W. C. Huntington, Mech.E., has resigned his position with the National Tube Co. to become commercial agent of the Bureau of Foreign and Domestic Commerce for the Chicago district. Address: Room 629, Federal Bldg., Chicago.

1908. George W. Hayns, Mech.E., was married Apr. 7, 1915, to Miss A. E. I. Wischhusen, of New York.

1908. William T. MacDonald, E.M., has taken a position with the Ray Consolidated Copper Co., Hayden, Ariz. He has been in Hurley, N. M., with the Chino Copper Co.

1908. R. T. Hirsch, E.M., has just returned to New York from a professional trip to assist in examination of placer deposits on the Rio Tocantins, in northern Brazil.

1908. Paul J. MacCutcheon, E.E., has been for several years manager of the electrical department of the H. W. Johns-

Manville Co., with headquarters at 100 Wood St., Pittsburgh. Address, 864 Thorn St., Sewickley, Pa.

1909. Louis G. Henes, Mech.E., was married in June, 1911, to Miss Evelyn Ellis, of Oakland, Cal. Address: 749 Oakland Ave., Oakland.

1909. D. B. Steinman, C.E., consulting engineer with Gustav Lindenthal, 68 William St., New York, has published a book on "Plain and Reinforced Concrete Arches" Wiley and Sons). Steinman is principal assistant engineer of the New York Connecting Railroad and in charge of the design and construction of a long-span bridge over the Ohio River for the Chesapeake & Ohio Railway.

1909. C. L. Bruns, E.M., engineer with El Cobre Mines, Santiago, Cuba, was in New York for a few weeks, early in 1915.

Henry W. Remington, Jr., Mech.E., is manager of the Paine Uptown Business School of New York, which recently celebrated its sixty-fifth anniversary. His home address is 354 Convent Ave.

1909. Lieut. J. A. Hoag, C.E., ordnance officer in the Coast Defenses at Panama, is stationed at Cristobal, Canal Zone.

1909. George E. Zabriskie, C.E., is in the chief engineer's department of the Interborough Rapid Transit Co. as transitman on duct line construction.

1909 and 1911. George W. Roddewig, E.M., and C. Eustace Dwyer, E.M., are on the engineering staff of the Federal Mining and Smelting Co. at Wallace, Idaho. Roddewig was married about a year ago.

1910. George E. Beggs, C.E., was recently appointed to the faculty of civil engineering at Princeton.

1910. R. E. Walters, E.M., is assistant manager of the Snowstorm Mine, Wallace, Idaho. He was married recently.

1910. W. E. Greenough, E. M., general manager of the Marsh Mining Co., at Wallace, Idaho, visited New York early in March on business for his company.

1910. S. L. Gunthorn, E.E., engineer for the Nachod Signal Co., Louisville, Ky., there. Address: "The Puritan."

1910. W. A. Lipstate, Chem.E., is chemist with the Jefferson Powder Co., of Birmingham, Ala. He has been elected a member of the legislative committee of the Alabama Section of the American Chemical Society.

1910. Frederick S. Dellenbaugh, Jr., E.E., began work in the sales department of the Westinghouse Electric and Manufacturing Co. at East Pittsburgh, Pa., on March 1, 1915. He has been with the Westinghouse company for two years.

1911. J. W. Lord, Mech.E., is back in New York, with the Kellar Mechanical Engraving Co., at 345 Fifth Ave., Brooklyn.

1911. Clinton Brettell, Mech.E., was married Jan. 6, 1915, to Miss Carrie V. Weiss, of New York. Address: 26 Nagle Avenue, New York.

1911. W. F. Peters, Jr., E.M., was married Apr. 14, 1915, to Miss Jessie Luella McCarney, of Buffalo. His home is now Park City, Utah.

1912. Harry Babcock, C.E., is in the foreign service department of the Standard Oil Co., of New York. He is located at Shanghai, China.

1912. W. A. McKnight has been awarded the Carnegie bronze hero medal and $1,200 for bravery. When on his way to college a few years ago he pushed two children from in front of a runaway horse at Broadway and Manhattan St., but was unable to save himself. He is now with the Aluminum Co. of America at Niagara Falls.

1912. N. R. Sethna, E.M., has been in England since June, 1914, studying English methods of mining. He is now with the Midland Coal, Coke and Iron Co., Ltd.

1912. Jay P. Woods, E.M., is with the Wanakah Mining Co. with properties at Ouray, Colo.

1912. Ivan P. Tashof, E.M., is secretary and treasurer of the Kentucky Mining Institute, Lexington, Ky.

1912. George A. Shaw, E.M., is now at the Champion mine office, Painesdale, Mich.

1912. K. B. Lamb, Chem.E., is with the United States Conditioning and Testing Co., 340 Hudson St., New York, as chemical engineer. He is specializing in textiles and paper, and editing the technical section of the magazine Silk.

1913. Frank H. Wagner, E.M., engineer with the Lehigh Valley Coal Co., was married June 17, 1914, to Miss Ailene M. Weppner, of Buffalo. Address: 61 W. Union St., Wilkes-Barre, Pa.

1913. A. I. Abrahams, E.M., formerly with the Nevada Consolidated, at McGill, Nev., and with the Canadian Copper Co., at Copper Cliff, Ont., returned to New York in April, and went to North Carolina to assist in sampling a mine.

1913. Elwin H. Findlay, C.E., is employed with the Standard Manufacturing Co., designing and detailing structural steel, also surveying, drawing plans and writing specifications for factory buildings. Address: 293 Vine St., Bridgeport, Conn.

1913. F. J. Patchell, E.M., is on the engineering staff of the Dome Mines at South Porcupine, Ontario.

1913. Walter Steinbruch, C.E., is with McMullen, Snare & Triest, Inc., who are constructing section 13 of the Lexington Avenue subway in New York.

1913. By order of the Supreme Court of the State of New York the name of Earl Hamlin Kirchgraber, C.E., has been changed to Rexford Crewe.

1914. Donald G. Campbell, E.M., was married Dec. 25, 1914, to Miss Catharine D. Brown, of Barre, Mass. Campbell is in the department of mining engineering of the University of Washington, at Seattle.

1914. Ray S. Wood, Met.E., is in the laboratory of the A. S. & R. Co., at Maurer, N. J.

1914. Clarence E. Meissner, E.M., is on the engineering staff of the Inspiration Consolidated Copper Co. at Miami, Ariz. He writes as follows of other Columbia men in the Miami district: "I am rooming with B. C. Staiger, '12. Tarantous, '12, is also here in the test mill. Rugen, '13, is with the Old Dominion in Globe. Bird, '14, and Eichrodt, '14, are at Morenci on drill work and living with Mampel, '14, and Grunow, '14, there. Kitson, '09, was here but left some time ago."

1914. Chester B. Sadtler, Met.E., is metallurgical engineer for the Rhode Island Tool Co., Providence, R. I.

1914. James A. Stewart is a mechanical engineer with the Francisco Sugar Co., Francisco, Cuba.

1867. Samuel Willard Bridgham, E.M., died at his home, 954 Fifth Ave., New York, Feb. 12, 1915, He was a son-in-law of William C. Schermerhorn, '40.

1884. Frederick Kidder Walbridge, E.M., died at Camden, S. C., March 14, 1915, aged 53. He was a resident of Brooklyn and New York, and a retired engineer.

1889. F. Augustus Heinze, E.M., died suddenly at Saratoga Springs, N. Y., on Nov. 4, 1914. His meteoric career as owner and operator of mines and smelters in Butte and vicinity is well known. While there he gained the good will of the miners by advocating measures in amelioration of their working conditions, and also gained the respect of his contemporary mine owners as an aggressive and resourceful opponent, both legally and politically. It is generally thought that he made a mistake in transferring his business interests to New York.

1900. David Carlyle Reed, E.M. died at Barranca, Peru, Jan. 6, 1915, aged 41. He had been engaged in railway engineering in Peru since 1911, after seven years work as chief engineer to Frank Klepetko in that country.

1906. Carl B. Franc, E.M., died at Gold Road, Ariz., March 15, 1915, from typhoid, after six years' work as mining superintendent there.

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THE

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DESIGN OF SURFACE COMBUSTION APPLIANCES*—I

BY CHARLES E. LUCKE.

Manufactured gaseous fuel is and always will be more costly per unit of heat carried than natural fuel, and yet may yield cheaper and better service, cheaper if the process and apparatus used for the combustion of the gas is efficient enough, and better if it is so designed as to liberate the heat in a sufficiently more available form. It is this fact that justifies the general interest now shown in the process that has been termed surface combustion, which promises both cheaper and better gas service, the realization of which depends on the accumulation of much new data for the design of commercial apparatus. The process of development that has resulted in the establishment of surface combustion on an engineering basis, whereby apparatus can now be designed to meet specific conditions, is reported briefly in this paper.

The new process assumes that gas to be burned should be supplied with no more air than will supply the required amount of oxygen for the combustion reaction, and that the air and gas should be thoroughly mixed previous to combustion, so that the reaction may take place instantly, once the ignition temperature is reached. Excess air is regarded as not only useless but harmful because of its heat absorption, which prevents the attainment of the highest temperatures, so desirable when the heat of combustion is to be communicated to other bodies, and carrying away as flue heat quantities that would

*Paper presented at eighth annual meeting of the American Gas Institute, October, 1913.

otherwise be of use. Premixture is regarded as desirable because thereby each particle of fuel may be brought positively into intimate contact with its required oxygen before it is needed, instead of depending on the accidental dissipation of the products formed on the edge of a flame jet, before the central core of gas can secure air from a surrounding and flame-supporting atmosphere. This premixture, in conjunction with suitable proportioning, prevents the escape of unburned fuel in any form. Thus, premixture of air and gas in combining proportions at once insures protection against two important sources of loss in combustion: that due to excess air and that due to incomplete combustion.

As an incidental accompaniment, another advantage of no less importance follows; that is, development of the heat of combustion in a form more available for absorption by the bodies to be heated, for the heating of which the gas is burned. Heat will be absorbed most readily from a fire when the temperature of the gases leaving the fire are hottest and when the fire zone is most radiant. All heat absorbed from a fire by direct contact of the absorber with the hot gaseous products is absorbed at a rate directly proportioned to the excess of the temperature of the gases over that of the absorber, so the hotter these gases are, the more heat will a given absorbing surface take up, other things being equal. Heat is, however, much more rapidly absorbed by bodies when the source is radiant, because radiant heat readily pierces the insulating dead gas films, adhering to the surface of the absorber and resisting, by its low thermal conductivity, transmission of heat from streams of hot gas. The superior transmitting power of radiant heat has been well known as long as physicists have studied the sun's rays, but it has been lacking in most, though not all, gas burners because of the very low radiant value of hot gases as compared with solid bodies at the same temperature. The premixture of gas and its supporting air makes it very easy to secure a large amount of the heat of combustion in a radiant form, because the combustion, being entirely independent of any atmosphere into which the products may be discharged, can be carried on behind layers of solid granules, in the crevices between them, in holes in solid plates, or behind solid plates of any convenient form, all of which, attaining the temperature of the gaseous

products of combustion, radiate heat at a rate immensely superior to that of the gases themselves.

With all these prospective advantages towards superior efficiency of gas burning apparatus, when the gas is supplied in the form of a premixture with its air in combining proportions, over all other modes of supply, the one question naturally arises as to why this has not been more commonly practiced, and once the idea is advanced, why there should be any delay in at once proceeding to the design of suitable appliances. The answer is to be found in the peculiar physical properties possessed by such mixtures over those now commonly in use, which make them difficult to control in the absence of detailed knowledge of these characteristic properties. In fact, without such knowledge, design of appartus is quite impossible, and it becomes feasible just in proportion as information of the needed sort is established by experimental research.

The fundamental peculiarity of such mixtures that renders control difficult is the property of self-propagation of flame through them, bringing them into the class of materials commonly termed explosive. As all the mixture is in a condition suitable for combustion, once the ignition temperature is reached, it naturally follows that, as the combustion temperature is much in excess of that of ignition, the burning of however minute a quantity of mixture at a point of ignition will promptly heat neighboring layers of mixture far above their ignition temperature, so that the flame will of itself proceed through the whole mixture if it be isolated in a chamber. The only way such self-propagation can be stopped is by preventing the heating of a fresh layer by the combustion of its neighbor, such prevention taking the form of a heat absorption by some solid screen at a rate rapid enough to permit the screen to take up the heat of combustion of all mixture in contact with one side, without itself becoming hot enough to warm the mixture on its other side to the ignition point. It is easy to make such flame-interrupting screens that will stop the propagation of flame through an explosive mixture once or twice, but difficult or impracticable to make them so as to continue to do this indefinitely. With the exception of the internal combustion gas engine, gas burning apparatus requires a continuous burning of gas as supplied to a definite place, termed the burner or furnace. When explosive gaseous

mixtures are supplied to such continuous fires, the property of self-propagation operates to defeat localization of the combustion unless specific means are provided in the design of the structure to make the treatment of the mixture conform to its physical properties, in which case the combustion can be more definitely localized than otherwise.

For any given mixture there is a definite normal rate of propagation which may be equal to, less or greater than the velocity of flow of the mixture into the fire, and it is clear that localization of combustion will depend primarily on the relation of these two rates, that of flame propagation and that of flow. If they are equal, that is, if the flame can burn back toward the source of mixture supply, just as fast as, but no faster than, the mixture reaches the flame, then will the flame remain fixed or be definitely localized. In fact, the above is the primary condition for localization of the combustion of explosive mixtures, because otherwise the flame would either travel back to the source of supply or be blown out by the faster flowing stream of mixture. Of course, localization may also be secured if the mixture be fed through a flame-interrupting partition at a flow rate inferior to that of propagation, in which case the localization takes place on the face of the partition, which must, of course, have a large capacity for heat absorption indefinitely, which means, in effect, that it must be able to dissipate or transmit to some other body the amount of heat is is receiving; otherwise, it would rise in temperature to the point where it, by igniting the mixture on the supply side, ceases to be an interrupter. Mixtures having this explosive property, of the sort that seem best from the standpoint of efficiency of apparatus, require a special treatment to permit their use in commercial apparatus, which special treatment has for its first object the definite localization of the flame. The means employed must, moreover, be so positive as to be unaffected by long continued operation, that is, the localization must be permanent.

Still other conditions are to be met, such as control of rate of comubustion per square foot of fire or per cubic foot of furnace, a cook stove requiring a low and crucible furnace a high rate, and as such mixtures have what might be called a natural rate corresponding to the normal rate of propagation, it is clear that specific means must be available for burning

slower or faster per square foot of cross-section of gas stream. Furthermore, any one burner or furnace, designed for some definite or normal rate of combustion or gas consumption, would be valueless commercially unless it would operate quite as postively at a wide range of variation, both above and below that normal rate. In other words, localization of the flame must not only be positive, and any desired rate of combustion be attainable by design, but in addition, hand or automatic interference with the designed rate of consumption must not in any way interfere with the localization. In some cases it is desirable that the burner be capable of reaching its normal or steady working state in a short time, as, for example, a domestic cook stove burner; while on the other hand a slow heating, corresponding to a large heat storage in the furnace, is necessary when articles are constantly being thrust in to be heated and then drawn out, without causing too much change of temperature in the furnace; hence control of heat capacity of the burner must be provided. Finally there must be mechanical means for making the desired mixtures and for maintaing the desired proportions, means so simple and automatic as to require no more skill or attention on the part of the operator than appliances now in use.

Accordingly, this review of the work of development of the first commercial surface combustion appliances is divided into the following heads:

1. Localization of combustion zone, initially on starting cold apparatus, and its permanency with the attainment of the steady state of the fire.
2. Rate of combustion per square foot of bed or hearth for high rates and low.
3. Control and adjustment of radiating surface.
4. Auxiliary apparatus.
5. Efficiency of surface combustion appliances.

The experimental work here reported has all been done by or under the direction of the writer, partly in his laboratory at Columbia University, but largely in the laboratory of the Gas & Oil Combustion Co. in the Chemists' Building. Only the results of New York City illuminating gas are here reported, though work has been done with other fuels, and results obtained permit the statement that all fuels in the gaseous or liquid form are equally available to the process.

1. Localization of Combustion Zone.

Reasoning from the fact that the flame cap, or surface over which combustion is proceeding, will be steady in location only when the velocity of the mixture approaching it is equal to rate of flame propagation for such mixture, the first step in the design of practicable apparatus is the formation of gas passages of suitably changing area, since the velocity of gas flow for small changes of pressure will vary inversely as the cross-section of the flow path. The mixture should approach the fire zone through a small tube or orifice at a rate greater than the normal velocity of flame, but immediately beyond there should be an enlargement of the cross-section of the passage to permit reduction of velocity, which, if carried far enough, will finally cause flow velocity to drop to equality with flame velocity, which was, at the point of entrance, in excess. Mechanical constructions that will permit of this can be designed in almost endless variety, many of them equally good, but for the best results certain precautions must be observed; notably, first, the tendency for a gas jet escaping from an orifice under pressure to resist sidewise expansion, so that even if the passage offers an increasing area for flow, the gas stream may not fill it unless forced to do so by baffles or their equivalent; and second, the tendency of free jets flowing through a gaseous atmosphere, consisting of products of combustion, for example, to entrain or diffuse with that atmosphere at the edges, becoming so dilute as to not burn properly, if at all.

Perhaps the simplest apparatus would be a very slightly tapering conical passage to which mixture is fed at the smaller end; the stream expanding sidewise to fill the cone would reduce in velocity and permit of the location of a combustion surface quite definitely. In time, such a conical tube would get hot; in fact at the section where the flame surface located it would become incandescent almost immediately if of refractory material, or melt off if of metal, and, of course, the narrower section along which the fresh mixture approaches would heat by conduction and would warm the feed gas. Heating the mixture would tend to increase velocity and push away the flame surface if another counter influence did not prevent it—increase in rate of flame propagation, which is due partly to rise of temperature and partly to the accelerating effect of the hot solid walls. This counter influence, tending

to accelerate combustion and draw the flame surface backward against the supply current is actually stronger than the pushing away effect of increased velocity due to expansion of the stream by heating. Such cones are not good forms for most purposes because of the limit imposed on the adjust-

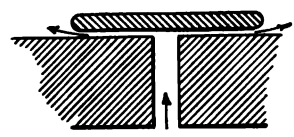

Fig. 1.

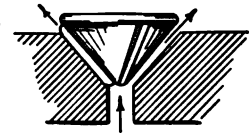

Fig. 2.

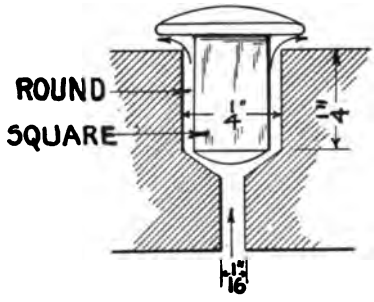

Fig. 3

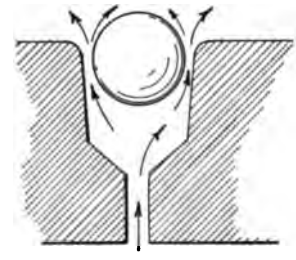

Fig. 4.

Fig. 1 to 4.—Means of reducing velocity to control localization of combustion surface.

ment of rate of supply which, if varied very much, would cause a blow off or back flash of the flame, unless the cone were extremely long. When, however, a steady-rate apparatus is needed, and flow is fixed, there may be just enough sidewise expansion of the jet issuing from a simple conical hole in a plate to locate the flame, but the practical uses of such apparatus are very limited.

To meet the needs of every-day service there must be a more positive localization of the combustion surface, insensible to variation of mixture pressure or flow rate, over a wide though definte service range, and this requires specific provision for baffling so that the gas stream will increase in cross-section rapidly beyond the supply point of minimum area and safe maximum flow velocity. Perhaps the simplest of these flame spreaders is a plate over the hole through which the mix-

ture escapes, as in Fig. 1. By placing the baffle away from the plate, containing the orifice, a distance equal to one-quarter of the diameter of the orifice, the stream direction will be turned through a right angle without changing the velocity until the stream moves out under the plate beyond the hole, when, of course, the velocity will be reduced inversely as the diameter of the circle which the gas occupies at any one time. With a hole $^1/_{16}$ in. diameter, a plate spaced $^1/_{64}$ in. away could reduce flow velocity, when cold, to one-eighth of its entrance value if the plate were ½ in. diameter. This would permit an eight-fold change in the rate of flow when cold, keeping the flame surface always under the plate, and give to the flame surface the form of a short cylinder. Such construction offers some difficulties, as in operation both plate and hearth would get very hot, and unequally so; at the center, the plate would remain dark, becoming incandescent from the flame zone out to the edge, which would crack most plates refractory enough to resist fusion even if a practical way of making such plates and holding them in position were available. An easier construction is shown in Fig. 2, in which a solid (alundum cement) cone with three small ribs is placed in a counterbore of the feed hole. This is self-locating when in the position shown, but not otherwise. Still another form which holds the baffle definitely against side movement is shown in Fig. 3, in which the baffle is shaped somewhat like a mushroom with a square-section stem which fits loosely in a round enlargement of the feed hole, so that the flow area does not change materially until the escaping mixture strikes the underside of the head and is deflected outward. The dimensions given are those used on some which gave good service with pressures up to 3 in. of water, though a little troublesome to make and apt to break if not gently handled. The most permanent form of the class of molded baffles is the refractory ball in a conical hole, shown in Fig. 4. It is interesting to note that the ball, remaining suspended in the jet and maintaining, by reason of its weight, a constant velocity of the jet around it, insures that the flame shall locate above it, keeping it cooler than otherwise, so that fire-clay balls have remained uninjured while the same clay, a short distance above, readily fuses. The physical action is here slightly different from the previous cases, the escaping mixture forming

an expanding jet of diminishing velocity between the ball and its seat.

While in these constructions, localization of the combustion surface is definte, and mixtures may be burned in combining proportions, all fail to produce uniform incandescence; a series of such baffles spaced uniformly approaches this result, but instead of a uniform glow gives a spotty appearance from black to truly incandescent. It was found that a porous screen of any sort, placed in the path of the escaping gases, will get uniformly hot. Three kinds of such screens have been used: 1, a perforated plate of metal, made of one of the non-oxidizable alloys such as are used in electric heaters; 2, a layer of granulated refractory material; 3, a diaphragm of bonded granular material, the most satisfactory of which were made of Norton alundum. Of course, the less mass given to the screen the more rapidly it reaches incandescence and in this respect the metal screen is best. One of these places ⅜-in. over a hearth 4½ in. diameter supplied with 35 holes each 1/16 in. diameter and ¼-in. ball baffles, heated in 6 sec., while diaphragms thick enough to be mechanically strong may take 5 min., though, of course, the latter are more durable. With the same arrangements, except that the mushroom baffles were used, the following consumptions of gas were measured at the corresponding pressures, giving a steady dull red at the lowest rate and correspondingly brighter at the higher rates: 7.25, 9.1, 10.9, 12.2, and 14.2 cu. ft. of gas per hour at 1.0, 1.5, 2.0, 2.5 and 3.0 in. of water pressure. A similar set of mushroom baffles set in a vertical hearth, and having a screen of crushed fused silica ⅝ in. deep, sized between 20/64 and 13/64 in., held in place by a second screen of wire mesh, heated to incandescence in 3½ min. at a supply pressure of 2 in. of water.

All the previously described baffling appliances intended to assist the spreading of the stream beyond the point of high velocity, and many others of the same class, are used to counteract the natural tendency of gas jets to remain intact and resist sidewise expansion. It is possible, however, to make use of this natural tendency of jets, and incidentally secure a very high degree of incandescence, higher in fact than is possible by any other known means. By moving the nozzle away from the baffle and making the baffle porous, (using, for

convenience in experimental work, a pile of refractory granules) the impact surface may be shaped to conform to the natural mushroom of the jet as it strikes. For any degree of porosity, jet velocity, or supply pressure, there is some best distance, and shape of impact face that permits all mixture,

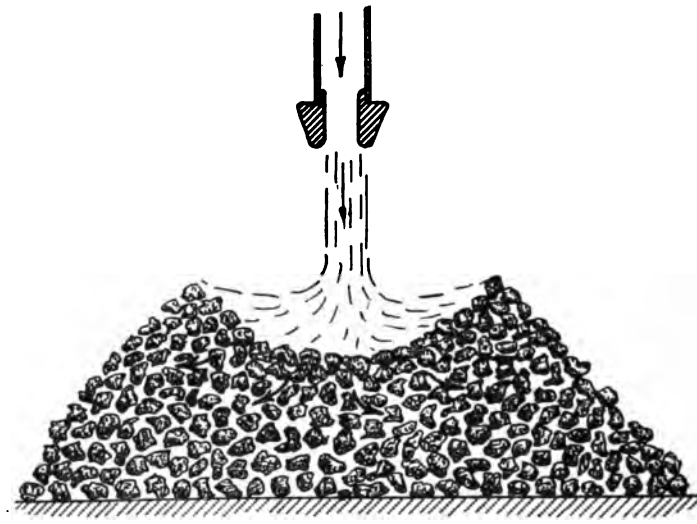

Fig. 5.—Means for localizing the combustion zone at the radiating surface.

whether striking at center or edges, to attain just the right velocity (that of propagation) in contact with the material, so that combustion takes place in contact with the outer or radiating surface, which then has the maximum temperature. It is essential that the impact face be porous, so that the products of combustion may readily escape through, instead of forming films, to separate the combustion surface from the solid faces and insulate the latter from the heat of the former. In this manner a surprising degree of radiance is obtained, due to the high rate of combustion of a mixture containing no excess of air, except possibly by entrainment at the outer edges. At 3.2 in. mixture pressure, 40 cu. ft. of gas per hr. were burned over about 4 sq. in. of surface, which corresponds to over 1,400 cu. ft. per sq. ft. per hour, or more than 800,000 B. t. u. per hr. per sq. ft. Higher rates of combustion than this are obtainable, but not all developed on the radiating surface itself.

In view of the importance of developing as large an amount of heat as possible in radiant form, in addition to the localization of the combustion zone, and considering that loose granules or porous diaphragms of refractory may serve the double purpose of radiating screen and of baffle or stream spreader, everything else may be abandoned in favor of these refractories, except perhaps for certain purposes for which special forms may be best. Nearly all the work done has been concentrated on an effort to learn how these granular beds and bonded diaphragms should be handled to yield commercial apparatus; and by reason of the simplicity of the loose bed it has been consistently favored over the bonded for most uses. A uniformly grained bed of loose granular material will act as a substantially perfect spreader of the mixture issuing from an orifice covered by the bed, but the quantitative effect of variations in size of grain, imperfections in shape or nonuniformity of size, together with shape of bed and its relation to shape, size and position of the feed orifice, are all to be determined by experiment only. Most of the detailed data of this sort will be omitted, as not of general interest, but the following series of experimental determinations illustrates the most important of the general principles that must be observed for successful operation.

One of the simplest arrangements is shown in Fig. 6, where a single nozzle 5/16 in. diameter projects 1¼ in. into a bed of broken fire brick; this material is very convenient for studying the ultimate position and shape of the combustion zone, as the material will fuse and bond at that place. The bed was held in a square brick box, 6¾ in. on a side and 5 in. deep; the nozzle was fed with mixture at 3.2 in. pressure. Starting with coarse grains, ½ to ⅜ in., the mixture, on ignition, flashed instantly down through the bed, locating quite near the nozzle, as shown later by the more or less spherical lump that fused together. The same action took place with smaller grains as they were reduced in size successively from ⅜ in. to 5/16 in., 5/16 to ¼ in., ¼ to 3 64 in., 3/64 to 5/32 in., 5/32 to 3/32 in., but a further reduction in size resulted in a different action. On using grains 3/32 to 1/16 in. size, the mixture, on ignition, burned on top instead of flashing down through the voids to its former position about the nozzle. In a few minutes the top layer became hot and then seemed to cool, but on

scraping away the top it could be seen that the combustion surface had receded. After running a sufficient time, this progressive heating from the outside down toward the nozzle resulted in a final position of the combustion zone about where it had been before, with the coarser material. In either case

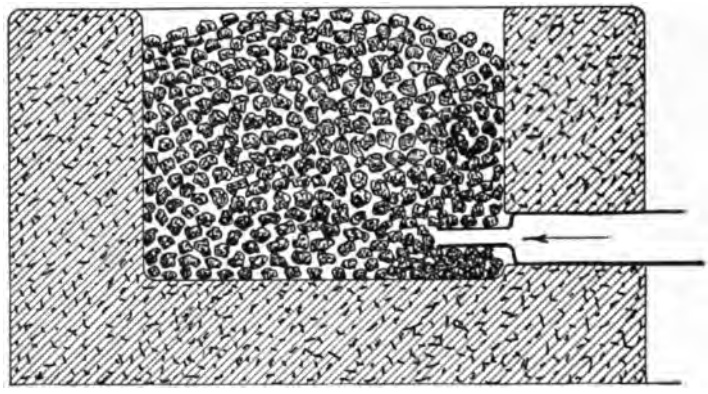

Fig. 6.—Apparatus for demonstrating spherical form of the combustion surface when mixture is supplied from a nozzle surrounded by granular refractory.

the whole bed became hot in time, but with coarse grains it heated from the normal combustion zone near the nozzle out and upward, while with grains small enough the outside top heated first, the flame drawing down slowly, a difference in action which requires an explanation.

When the grain is fine enough it acts like a flame-interrupting screen, each little crevice between neighboring grains discharging so little mixture that its heat of combustion can for an appreciable time be absorbed by the solid grain without raising the lower side to the ignition point, radiation from the outside surface helping to keep down the temperature. In time, however, the lower side of the top layer gets hot and the combustion surface recedes, doing so more rapidly once it has passed under the top layer, because then radiation is lessened, leaving more heat for the grain to absorb. It follows also that, with the finer grains, less mixture will escape from such a round nozzle as the grains tend to fill the orifice, so the total amount of heat developed will be less than with coarse grains. To show that the difference in flame action

is due not so much to the stoppage of the nozzle by the finer grains as to the difference in the flow of gas through the bed itself, with more intimate contact between mixture and grain, the smaller the latter, the same series of results was obtained in a pyramidal chamber, Fig. 7, in which the nozzle was formed

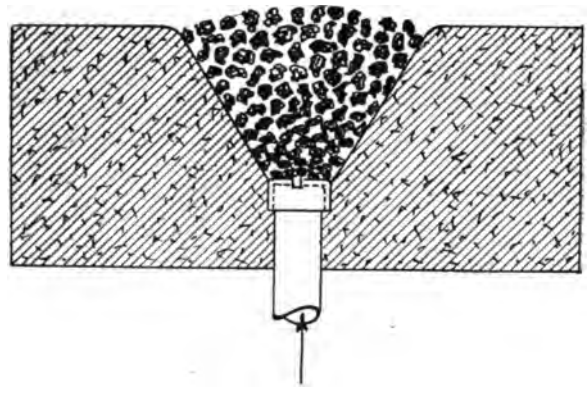

Fig. 7.—Apparatus for demonstrating uniformity of position of combustion surface with different sizes of grain.

by a pair of hacksaw cuts in a 1-in. pipe cap. With such outlets, the flow was substantially the same for all the different sizes of grain, yet not only with the 3/32 to 1/16-in. grain did the top heat first, but also with the larger 5/32 to 3/32-in., with which it required 10 min. to draw the combustion zone down through the bed to its normal place and fuse a lump of granules over the cross slot.

In establishing the action just described, the use of firebrick grains was most satisfactory, as each test gave a record of what happened in the form of a fused lump, but once it was clear that the size of the grain made only an initial or temporary difference in action, then longer runs became desirable, to ascertain the possible heating effect on the nozzles, and for these long runs refractory grains were used, including magnesite, chrome ore in both natural lumps and broken brick, fused silica, lime, and alundum. With these materials, the long runs showed that some forms of feed orifices became heated so as to ignite the mixture in the feed pipe, while with others this action did not take place, permitting operation for an indefinite time. It was not clear at the time just what

caused the trouble, since it frequently happened that the nozzle that worked best was really much hotter than another that flashed back almost as soon as the steady state was established. At any time, an increase in the pressure at which the mixture was supplied would have so increased the volume of flow as to drive the combustion surface to a safe distance from the nozzle, but it was deemed unwise to leave the matter here, because, first, all domestic apparatus must operate on low pressure, lower than that of gas in the local mains; and second, all industrial apparatus, for which the boosting of gas pressure would not be objectionable, would at some time be operated at part capacity or turned down, which is equivalent to low-pressure operation.

The next question investigated, therefore, was the permanent localization of combustion zone, and the discovery of means for securing an indefinite length of operation, without disturbance from long continued heating, even over several days, and with mixture pressure so low as to permit the hearth end of the nozzle to become heated above the ignition temperature. It was clear at the start that iron, or any metal, must be kept away from the feed orifice proper, and that the mixture must enter the fire chamber through a refractory orifice, or when the burner is lined with refractory, as it should be, it must enter through a hole in the lining, or what might be properly called the hearth. A long series of experiments was made with different shaped orifices; results for a time were extremely puzzling, but finally could be summed up in a very few words. All feed holes will become incandescent at the fire end, with low gas pressures; heat will flow back through the bounding material of the hole and these hot walls will heat the mixture passing through. No harm will result, however, even from a bright red heat on the walls of the hole, provided the latter is of uniform bore over the heated part and has no enlargement of cross section, with corresponding low velocity, except at points which never get hotter than the ignition temperature. To put it differently, the mixture passageway may be at any temperature without harm if of uniform bore, and if, when cold, the flow velocity is great enough to prevent back-flash. Under these conditions, localization of combustion will be permanent. Naturally, anything that will reduce the temperature of the supply tube,

like radiation in the air, will also shorten the necessary length of uniform bore, as will also the use of more non-conducting material. Finally it was found that the length of uniform-bore feed pipe that would remain cool enough at its supply end to be joined safely to a larger mixture header was

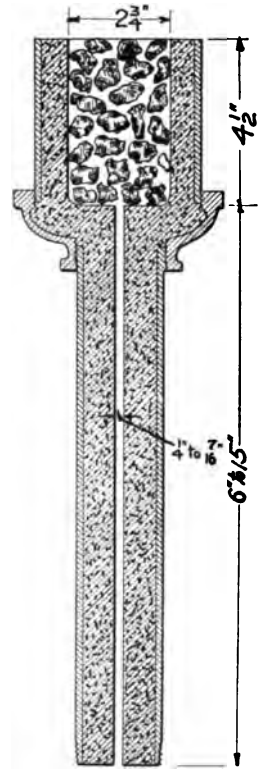

Fig. 8.—Apparatus for determining the ratio of length to diameter of feed hole to control "Back Heating."

greater for large than for small holes, and that the allowable length was a definite number of diameters. For example, in the apparatus illustrated in Fig. 8 with a single refractory-lined tube feeding a cylindrical combustion chamber, all of alundum cement encased in metal, a hole of ¼ in. diameter and 6 in. long could be operated indefinitely at 1-in. water pressure even after the chamber had been made very hot by previous operation at much higher pressure; whereas a $^{7}/_{16}$-in. hole

of the same length flashed back at 1.5-in. water pressure, and continued to do so after periods ranging about three hours, even after its length had been increased to 15 in. Small-diameter orifices of, say, $^1/_{16}$-in. diameter have, on the other hand, been operated indefinitely on pressure as low as 0.2 in. of water when about 1½ in. long. Back-flash after long periods of operation, due to heating of the supply system, may, therefore, be prevented by proper design, that is, by selection of suitable proportions in accordance with the established data, and localization of the combustion zone will be correspondingly insured against disturbance.

2. Rate of Combustion per Unit Area of Bed or Hearth.

The next question of importance is that of controlling rate of heat generation per unit area of fire bed; this involves the distribution of the burning mixture over surfaces as large or small as may be demanded, and the maintenance of high or low degrees of incandescence over these surfaces. This now seems a very simple matter, but for a considerable time it semed even more elusive than the prevention of back-flash through nozzles. There are really two problems here and, though related, the relation is not so clear as it might seem. First, at how high a rate may gas be burned and how may the structure be formed so as to permit steady supply and combustion at this rate over any given surface; second, the problem of low rate, can such mixtures be burned so slowly as to keep a surface just hot enough for frying, for example, and may such a burner be turned down to a simmering point without giving trouble, and, if so, what ideas must be incorporated in the construction?

The problem of the high rate is the simpler of the two, as this may properly be termed the natural rate, assuming, of course, that suitable refractories are obtainable for the corresponding high temperatures, and that the principles of permanent localization of the combustion zone are understood and incorporated in simply constructed apparatus. When the whole cross-section of bed is taken up by the burning gas stream, or when the combustion zone occupies the whole of the bed cross-section, then mixture is being supplied as fast as it can be burned within the space available, and any increase in rate of supply will tend to push the combustion zone away,

or result in blow-off. This is the condition at the limiting high rate of combustion, and is the natural rate because the advancing stream of mixture fills the whole available cross-section of fire zone. To establish this high rate it is necessary that the mixture be supplied, at first when everything is cold, at a lower rate; after the bed is heated, its accelerating effect may be relied upon to hold localized a very much increased rate of supply, up to a certain maximum, which is the natural or high rate of combustion. This natural high rate is intimately related to the pressure of the mixture at the point of supply, or more properly, the drop in pressure through the feed orifices, for holes of any given size. For example, in such a simple apparatus as that of Fig. 8, where a single feed hole supplies a combustion chamber of larger cross section, carrying a loose granular bed, it is evident that at some low pressure the combustion surface will just cap the feed hole, and the rate of combustion will be natural for a bed area equal, not to the actual bed of 2¾ in. diameter, but to that of the feed hole, a fraction of an inch in diameter. Increase of supply pressure will push the combustion surface away from the hole until finally it will extend across the whole bed and have a form approximating a section of a spherical surface lying within a cylinder, the axis of which passes through the center of the sphere, the latter being located at the center of the feed hole. It is this latter condition that gives the high rate, and to secure it the supply pressure must be enough to send through a small feed hole, say ¼ in. diameter, enough mixture to spread out and fill the voids in the bed of 2¾ in. diameter, which will exceed half the whole cross-section, while at the same time the flow velocity through the enlarged cross-section must be as great as the rate of flame travel backward. If the ratio of bed area, with a given percentage of voids, to feed-hole area is large, then high pressures must be used to secure the natural high rate; hence if only small pressures are available then the free flow area of the bed may not exceed the area of the feed hole by very much. In any case, large beds can be heated, at the high rate of combustion, only by multiplication of orifices spaced at distances equal to the diameter of the combustion surface natural to the supply pressure in use. Before such spacing of feed holes for high natural rates of combustion

can be found, it is first necessary to investigate the action for a single hole in a given bed, to find the relation between feed pressures and the ratio of active bed area to feed hole area that will cause the combustion surface to fill the whole bed between the enclosing walls.

As an illustration of the method of procedure, it being impossible here to record much of this sort of data, the results of a single series on the apparatus shown in Fig. 8, will serve. In this series the pressures were never extended above 12 in. of water at the point of supply, and began with a single hole $^5/_{16}$ in. diameter, discharging into a cylinder 2¾ in. diameter, area 6 sq. in.; but as increase of pressure to the maximum noted failed to supply as much mixture as could be consumed in the available area, there was added a second, a third, and finally a fourth hole, even then not reaching the limit. With the four holes, and at a pressure of 10½ in. of water, a rate of combustion was attained of 2,460 cu. ft. of gas per sq. ft. of bed per hr., which on a calorific value of 600 B. t. u. per cu. ft., was equivalent to 1,584,000 B. t. u. per hr. per sq. ft. There was no indication that the limit had been reached, but as the rate was high enough for practical purposes, so high as to give trouble with available refractory materials, this series was not carried beyond these limits, though it could easily have been done with higher pressures or with a larger feed area than four $^5/_{16}$-in. holes, or 0.3 sq. in. The conclusion here is, that rates higher than have been known are easily obtainable, rates higher than any refractory in common use can resist, and if any service arises that requires such rates, the demands can be met.

It might be noted here that of several refractories tried, the most satisfactory was white alundum, with linings of alundum cement, preferably mixed with alundum grain of several sizes, properly proportioned dry to fill the voids, then mixed wet, rapidly dried and finally baked at a bright red heat. The size of grain in the loose bed, and the depth of bed, do each exert an important influence within limits, but in general, for these high rates the larger the grain the better, though there is little if any advantage beyond 1 in. diameter, the depth in any case being little more than sufficient to prevent the gases from lifting the grain off the hearth. The resistance in the bed is always materially less for round grain

than for flat, and in this respect the form of fracture of white alundum is most satisfactory. In the above mentioned series, white alundum from ½ to ¾ in. diameter was used and the depth averaged 2 in.

Probably the most difficult of these experimental problems was that of finding a suitable device for the permanent localization of the combustion surface for very low supply pressures, while at the same time securing any desirable low rate of combustion over the bed, with a uniform incandescence at the surface, such as would be suitable for cooking, for example. It is clear that the lower the pressures the closer to the feed hole will be the combustion surface locate, the smaller the area of bed heated, and the stronger the tendency to back-flash. This fact led to early attempts to secure low-rate heat distribution by other means than that of feed holes giving a series of spots, each having natural high rates of combustion, and located practically at the mouth of the hole. Mixture supplied to a passageway filled with fine granules, or a porous brick, will flow much the same as through a pipe, since the porosity supplies a multiplicity of small paths more or less mutually communicating, and a given quantity would flow through such a porous layer at the same mean velocity as through a pipe having cross-section equal to the voids, except for differences in friction. Mixture fed into such a bed in any convenient way, ranging from a single hole under a thick bed to a great number of holes under the whole bed, obtainable by a metallic screen support for loose granules, or the under surface of a bonded diaphragm, would discharge the mixture uniformly from the top of the bed, however the supply was arranged, if the bed were thick enough. This seemed at first the most promising idea for low-rate heat distribution, especially as changes of flow area so necessary for localization can be obtained by two means, quite conveniently; first, by using two layers, the upper being coarser and, therefore, having more voids than the lower fine bed; second, by changing the diameter of the containing walls that hold the porous bed.

At first, only loose granules were used in apparatus such as shown in Fig. 9, where a perforated metal plate of 306 holes per sq. in., diameter 0.033 in., and 27.8% free opening, is supplied by a ¾-in. pipe, discharging into a conical space under the screen. On top of the screen rests a 1-in. bed of granules

1/8 to 3/32 in., and over it another 1-in. layer of larger grain, 3/8 to 5/16 in. diameter. On lighting the mixture, supplied at 2 in. water pressure, the combustion zone instantly locates between the layers at the point of change of flow space, due to the difference in voids, but as the heat penetrates the lower

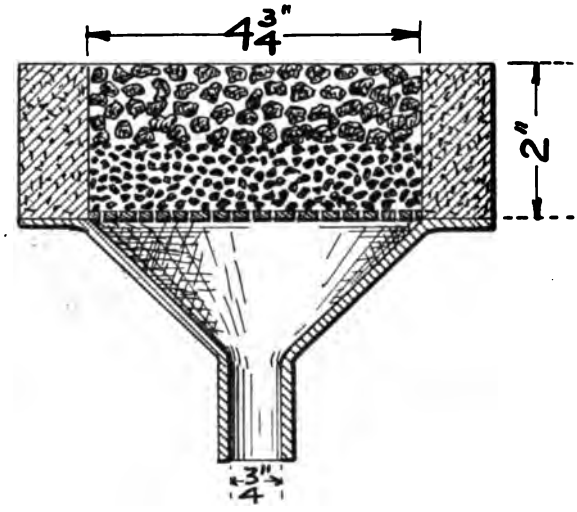

Fig. 9.—Means of controlling surface distribution of heat by mixture supply to fine granular bed on screen.

bed, the combustion zone works back to the screen, which happens, with these conditions, in about 10 min. All sorts of changes in the relative sizes of the material and thickness of the two beds, or number of layers, yield no difference in the result except as to the time it takes the combustion zone ultimately to work back to the screen, burning it out, or causing a flash-back, or both. This is clearly due to insufficient velocity of flow at the supply end of the bed and suggests a contraction of the walls toward the lower end, as in Fig. 10, where a slot supply is substituted for the screen, as it does not burn out so readily if by accident the flame should work down that far. As before, however, the combustion zone worked down close to the nozzle but not so quickly as before, suggesting a further narrowing at the bottom to form a neck as in the forms successively tried, as shown in Fig. 11, 12 and 13. As the neck is thus narrowed, the combustion surface no longer approaches the nozzle so closely, stopping in Fig. 11,

for example, about 1 in. above after ¾ hr. at 3½ in. pressure, and in Fig. 12 stopping about 1½ in. above, while in Fig. 13 it did not enter the lower cylindrical portion at all.

By adjusting the space between the walls, the flow velocity through the lower fine bed can, therefore, be kept high enough

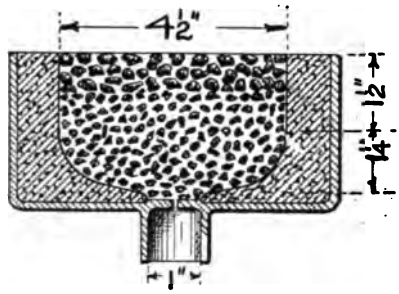

Fig. 10.

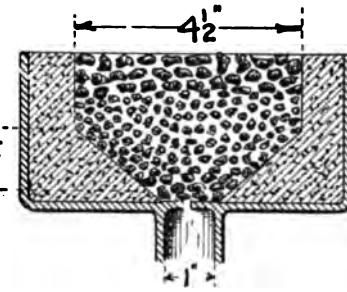

Fig. 11.

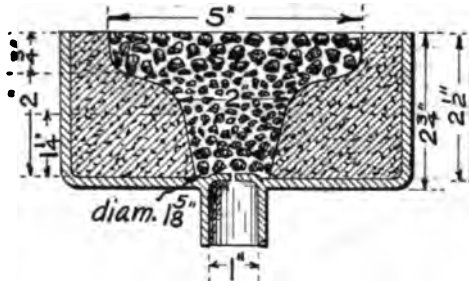

Fig. 12.

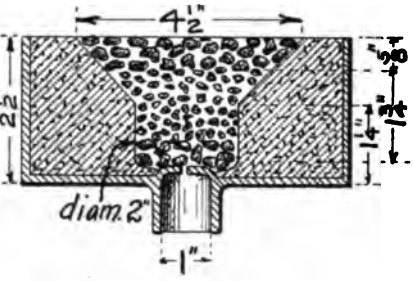

Fig. 13.

Fig. 10 to 13.—Apparatus for controlling position of combustion surface for a given heat distribution over the radiating surface.

to control the location of the combustion zone, regardless of the manner of feeding the mixture to the narrow bottom part, but the problem is by no means solved. All these latter forms are bad in another respect because, owing to the thickness of bed above the combustion zone, the top is hot in the center and cool at the edges. To get an even top heat, a greater thickness of bed above the combustion zone would be required, but this is already too thick to permit a quick initial heating. An alteration was made by enlarging the cylindrical portion and inserting a solid core of 3½ in. diameter so that the mixture rose in a ring ¼ in. thick around the core, filled with fine material, and then spread out at the top, heating

a bed of 5 in. diameter. This gave a better top heat distribution but took too long to reach a steady state—almost an hour. After many trials of various proportions it became clear that, if uniform top temperatures are to be obtained quickly with low rates of gas consumption over extended surface, single feeds through single or double porous beds will not suffice, and some other plan must be employed.

The failure of the single-point supply to distribute mixture so as to not flash back and yet quickly and uniformly heat the top of a radiating bed, with a low rate of combustion, leads to the conclusion that multiple feed orifices must be used, so spaced as to give the heat distribution desired at the available pressure, a surface bed or radiating screen of sufficient thickness serving to localize the combustion and to equalize the otherwise spotty appearance. It might appear that this could be done by drilling holes in a plate dividing the combustion chamber from the mixture supply chamber, but from what has been said about the conditions of permanent localization of combustion zone, it is clear that such an orifice plate will sooner or later heat through, becoming hot enough on the supply side to ignite the mixture there before its entrance into the feed holes. Any sort of feed-hole plate is out of the question unless provided with means for removing heat received on the combustion side fast enough to prevent the other side from becoming a point of ignition.

It has been shown that a single long feed hole, supplying a combustion zone can be proportioned so as permanently to resist backward flow of heat well enough to insure indefinite periods of operation; so it naturally follows that several feed holes might be grouped so as to be fed from a common point, discharging mixture at their other ends over as large an area as needed for any desired surface rate of combustion, and so proportioned as to resist heat flow as effectively as with one, if the necessity for the latter is kept clearly in mind. This conception is the basis of the construction shown in Fig. 14; this has 34 holes, molded in alundum cement by $^1/_{16}$-in. wires held in hole plates at the ends, radiating from a 1½-in. bottom chamber in the cast-iron container to a 4¼-in. circular top bed. To insure the supply end of these feed holes against a rise of temperature to the ignition point, it is necessary only that the distance between this chamber and the hearth be long enough.

When it is, the dissipation of heat from the side walls will be rapid enough to balance the heat carried down through the solid material surrounding the holes, and the dimensions shown in the sketch have proved to be adequate for this purpose.

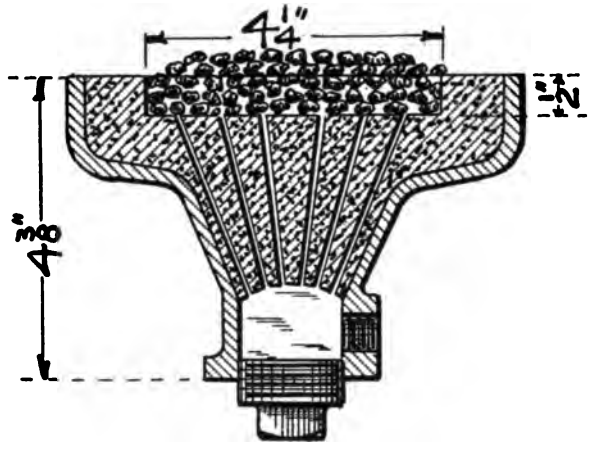

Fig. 14.—First cook-stove top burner, in which localization of combustion surface, back heating, distribution of heat over radiating surface, are all controlled.

This arrangement gave a quite uniform top heat and was operative at low pressures for an indefinite time, for, although the holes of the central group were often red hot for over 1 in. below the hearth, the heat dissipation from the sides was always sufficient to prevent the lower end of the holes from ever reaching ignition temperature. The proportions used were selected to give consumptions somewhere near those of the standard top burners of ordinary gas cook stoves; that is, at pressures of 2½ in. water the consumption was intended to be about 15 cu. ft. of gas per hr., which is equivalent to about 100 cu. ft. of mixture. Naturally, variations in thickness of bed, size of grain, or even kind of grain, will cause changes of resistance, the latter due to variations in the voids corresponding to different characteristic fractures, silica, for example, tending to form flat faces while white alundum breaks more nearly round. By varying the diameter, length and spacing of holes, keeping the general arrangement here indicated, practically any desired rate is obtainable, though the general

design is the result of the search for a construction suitable for a properly distributed low rate of combustion.

To illustrate the ease of adaptability of this general type of surface combustion burner to any desired rate over any surface, two other burners are shown, designed for a muffle fur-

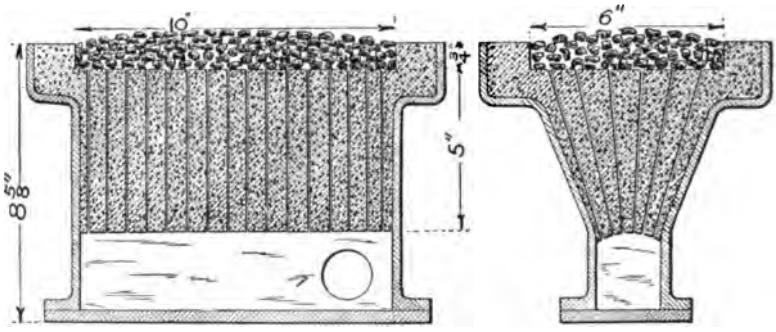

Fig. 15.—First form of muffle furnace burner, solid type.

nace, and a crucible furnace, respectively. That intended for placing below an assay muffle is shown in Fig. 15. This burner had a rectangular hearth, 6 by 10 in., supplied by 96 holes, molded in alundum cement in a cast-iron casing; at 3 in. of water pressure it consumed 120 cu. ft. of gas per hr., over 60 sq. in., equivalent to 288 cu. ft. per hr. per sq. ft. A still higher rate over an annular hearth was obtained in the small crucible furnace burner of the same general type shown in Fig. 16, the combustion zone lying between the side insulation and a central cylindrical muffle used to keep the crucible chamber clear, but not at all essential to the operation, though it helps to keep the crucible bottom cooler than it otherwise would be. In this burner 20 holes, each of 0.14-in. diameter, were distributed so as to be on the surface of a cone supplying a hearth lying between two circles, of $4\frac{1}{2}$ and $2\frac{3}{4}$ in. diameter, the area of which is, therefore, $15.9 - 5.9 = 10$ sq. in. The consumption was 40 and 47 cu. ft. per hr. at 2.5 and 3.0 in. respectively, which are equivalent to 576 and 677 cu. ft. per sq. ft. of hearth.

While the molding of groups of feed holes in tapered banks, long enough to keep the mixture chamber from reaching the ignition temperature, is a perfectly feasible mechanical construction and capable of insuring indefintely long operation at

any desired rate of combustion, it has certain disadvantages. In the first place, it is somewhat troublesome to mold the plastic material between casing and wires so as to secure a solid mass that will not crack on subsequent unequal heating; and, when large, these sections are very heavy and easily broken

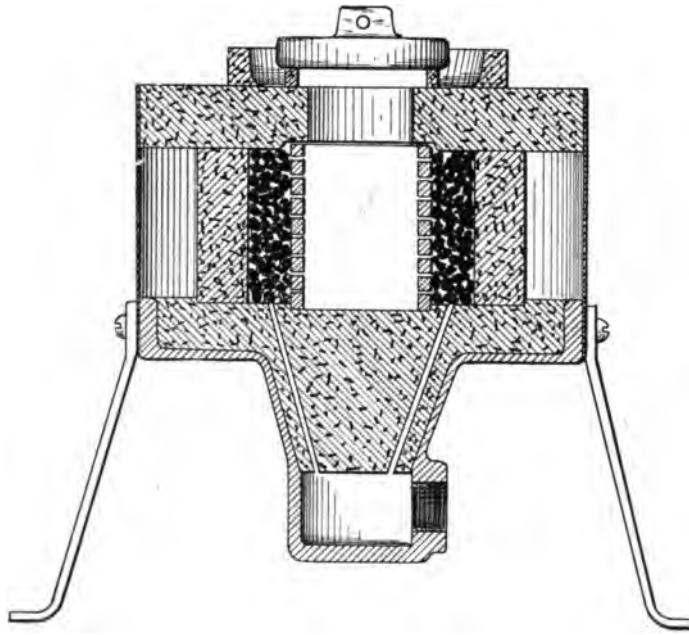

Fig. 16.—Construction of small, solid-type muffle furnace.

by shocks that may come when setting them in place. They are, moreover, necessarily high, too high for many locations, such as a cook stove or boiler furnace, if present proportions of frames and settings are to be maintained. These, with some other minor objections, are sufficient to warrant a search for a better form.

Fortunately, a better form and one that is completely satisfactory in all respects, has been found, following naturally from a little analytical reasoning. The holes through which the mixture is to be supplied must be cooled, and the cooling must be effective enough to keep the supply end above the temperature of ignition, but no more cooling than will do this is necessary or of value. In addition, the holes must be spaced

at the hearth for proper distribution of heat and the desired rate of combustion per square foot of hearth. Banking them in groups, as has been shown, will accomplish this, but it is clear that complete or partial structural independence of the holes, by forming them in tubes so each may be cooled inde-

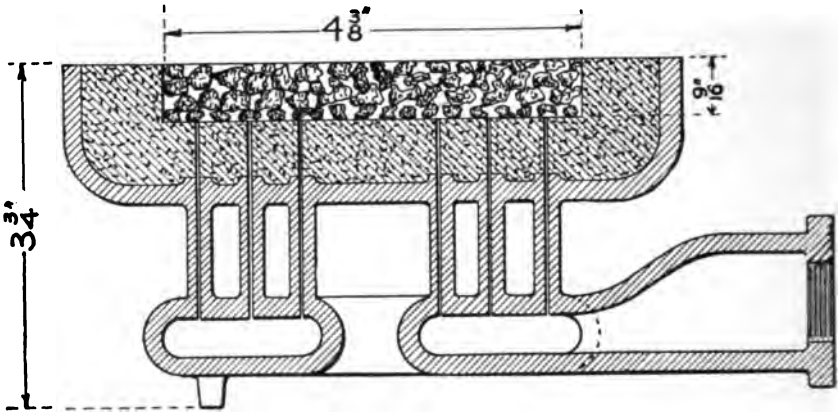

Fig. 17.—Second typical form of construction of cook stove burner (top). Heat distribution controlled by spacing feed holes. Rate of combustion by number and size of holes. Localization by velocity reduction at outlet from holes; and back heating by separate cooling of the walls of each hole.

pendent of the others, or even forming them in ribs with independent cooling in at least two directions, is better and more effective than a form in which the heat is to be dissipated from an inner hole must be conducted past an outer one, also developing heat of its own.

Accordingly, this principle has been incorporated into the construction of burners that seem in every way to be satisfactory commercial forms for all sorts of surface combustion apparatus. The first of these, designed as a top burner for a domestic cook stove, is shown in Fig. 17. A feed hole is first drilled in each of the separately cast posts. To place the lining, wires are inserted in the drilled holes while pressing the cement in place, thus forming a perfect hole in the hearth, exactly registering with the drilled hole in the casting. This burner has 35 holes, each of 1/16-in. diameter, but other diameters have been used, as well as other materials for the bed, and of all thicknesses, and, while consumption and top tem-

perature vary with each, practically everything works well, and any result desired by the designer is obtainable by simple selection of suitable dimensions.

This same principle of supplying mixture through more or less independently cooled feed holes, formed in metal walls and discharging into registering holes in refractory hearths, has been applied to higher-rate appliances than those of domestic service, such as muffle and crucible furnaces. By drilling feed holes in ribs, the same casting can be used for a wide range of capacities by changing drill sizes and center distances. For an assay muffle, a few separate tubes are placed at the side and front to develop enough extra heat to counteract the cooling due to the open front end, and equalize the temperature throughout the muffle. At one side is placed a single-orifice sampling burner with open bed, consuming 2 ft. of gas per hr., and used to adjust the mixture proportions, slight changes in which are readily recognizable by the appearance of this small open fire. The main burner is operated normally at 116 cu. ft. per hr., and always gives a very good thermal gradient, as shown by the following figures. The

Thermal Gradient in Muffle with Flue at Top Front.

Distance from front of muffle	Door closed, no draft. Temp. °F.	Door open, good draft. Temp. °F.
2 in.	1,760	1,600
4 "	1,870	1,742
6 "	1,900	1,820
8 "	1,910	1,852
10 "	1,900	1,840
12 " (back)	1,900	1,820

really significant feature here, however, is the ease with which any gradient desired can be obtained by changing the quantity of mixture supplied at different points, entirely independent of flue location. The crucible furnace is fed with two rows of holes drilled in a series of radial ribs and discharging in the annular space between insulation and muffle. The mixture holes discharge into a hearth of alundum cement on which rests the cylindrical alundum muffle. It is not difficult to consume in such a furnace enough gas to produce temperatures that will soften any available refractory, but by simply

changing mixture pressures it is easy to maintain practically any temperature desired. If, for any special purpose, it should be necessary to maintain a secondary hot zone at any particular point, then separate mixture supplies can be led to that point and burned without interference by the products of combustion passing from another combustion zone, a condition peculiar to surface combustion, to which the well known "smothering" of common bunsen flames is unknown.

(To be concluded.)

NOTES ON THE OCCURRENCE OF ANHYDRITE IN THE UNITED STATES

BY AUSTIN F. ROGERS.*

Though a common mineral in Germany, Austria, and other parts of Europe, anhydrite is usually considered a comparatively rare mineral in this country. In Dana's "System of Mineralogy" (6th ed., 1892, p. 912) only three localities within the United States (Lockport, N. Y., Darby tunnel, near Philadelphia, and Nashville, Tenn.,) are mentioned, and these are insignificant occurrences, of mineralogical interest only.

Without making an exhaustive search of geological literature, the writer has been able to find reference to the occurrence of anhydrite in nearly one-half (22) of our states (about 60 localities in all). In many of these localities anhydrite occurs in thick beds in abundance, and hence must be considered a common mineral, not merely a mineralogical curiosity. It is, in fact, a rock-forming mineral of some importance. As G. S. Rogers [1] has recently emphasized, the petrography of the sedimentary rocks has been neglected. The fact that the writer has had an opportunity to collect and study anhydrite in a number of widely separated localities in the western part of the country (Kansas, Colorado, Nevada, and California) within the last few years, accounts for the present paper.

Because of its general similarity to gypsum and to limestone, anhydrite is somewhat difficult to recognize at sight, and has doubtless been overlooked many times. While anhydrite and gypsum are similar in a general way, and may easily be confused by careless observers, they are quite different in properties. These differences may be tabulated as shown on following page.

The following comparison is one of the best examples of the dependence of physical properties upon chemical composition. While anhydrite and gypsum are somewhat similar they may be distinguished by about eight different tests given in the tabulation. The hardness of gypsum is usually given as 2; the

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[1] Jour. Geol., vol. 21, pp. 714-727 (1913).

hardness of the distinctly crystallized varieties is 2, but compact varieties run above this, for often they are not scratched by the finger nail. In massive compact varieties, specific gravity is a better means of distinction than hardness. Of the various tests tabulated, the optical properties are the best, for the two minerals may be distinguished in the pres-

Anhydrite, $CaSO_4$	Gypsum, $CaSO_4.2H_2O$
Orthorhombic.	Monoclinic.
Cleavage, pseudo-cubic.	Cleavage, perfect in one direction.
Sp. gr., about 2.9	Sp. gr., about 2.3
Hardness, 3 to 3½.	Hardness, 1½ to 2½.
Fragments are square or rectangular, with parallel extinction.	Fragments are platy with oblique extinction, or have aggregate polarization.
High relief in clove oil or balsam ($n\gamma = 1.614$; $n\alpha = 1.571$).	Low relief in clove oil or balsam ($n\gamma = 1.529$; $n\alpha = 1.520$).
Double refraction, rather strong; max. value, 0.043.	Double refraction, rather weak; max. value, 0.009.
Soluble with difficulty in dilute HCl.	Easily soluble in dilute HCl.
Little or no water in closed tube.	Abundant water (20.9%) in closed tube.

Fig. 1. (x35 diameters) Anhydrite in Crushed Fragments.

ence of each other. The optical tests may be made with crushed fragments[2] as well as in thin sections. Fig. 1 represents the square and rectangular cleavage fragments. The diagonal twinning lamellae are characteristic.

[2]A. F. Rogers, School of Mines Quarterly, vol. 27, pp. 340-359 (1906). A. J. Moses, Ibid, vol. 34, pp. 305-334 (1913).

CENTRAL KANSAS.

In 1908 the writer [3] found anhydrite in some abundance on the dump piles of the salt mines at Kanopolis, Ellsworth county, and at Lyons, Rice county. It had previously been reported by Willard [4] from Kingman, Kingman county. At these localities anhydrite occurs in fine-grained gray or pink rock masses which are probably lenticular layers interbedded with red shales. The anhydrite often occurs intimately associated with halite. Cleavable, columnar, and fibrous varieties occur in seams of the anhydrite rock.

Fig. 2. (x60) Pink Massive Anhydrite, Kanopolis, Kas.

The specific gravity of the pure, massive anhydrite from Kansas varies from 2.92 to 2.98. Fig. 2 is a micro-photograph of a thin section of pink massive anhydrite from Kanopolis. The slide shows but one mineral, anhydrite, which occurs in rectangular subhedral crystals with rather high relief. The specific gravity is 2.92. Gypsum occurs on the exterior of the hand specimen but none is observable in the slide.

Fig. 3 represents a more common type of anhydrite rock. While anhydrite is the dominant mineral, gypsum also occurs. The specific gravity of this specimen is 2.62. The thin sec-

[3] Trans. Kan. Acad. Sci., vol. 13, p. 78 (1891-2).
[4] Amer. Jour. Sci., vol. 29, pp. 258-261 (1910).

tion proves that the gypsum (mineral with low relief) is an alteration product of the anhydrite (mineral with rather high relief). The mineral with very high relief, near the center, is dolomite; this is doubtless a chemical precipitate from sea water, the same as anhydrite.

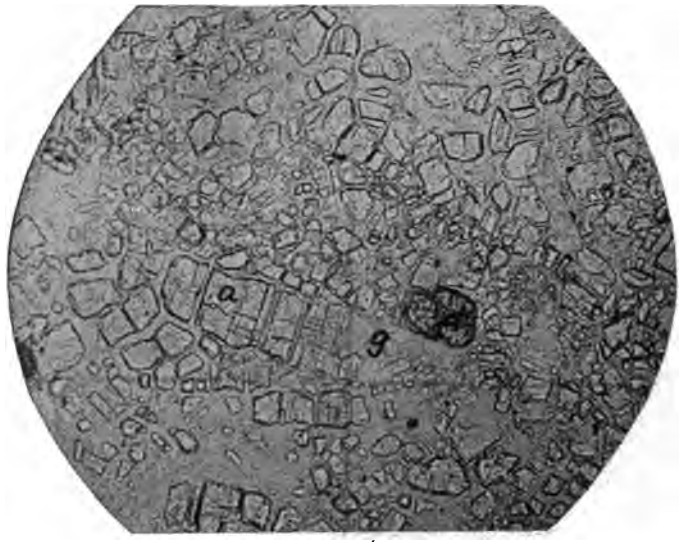


Fig. 3. (x80) Anhydrite Rock, Kanopolis, Kas.
a, anhydrite; g, gypsum; d, dolomite.

EAGLE COUNTY, COLORADO.

In the region around the town of Gypsum, Eagle county, gypsum is a prominent mineral and rock. Burchard [5] has described the gypsum deposits of this region. The writer spent a day in this vicinity in August, 1913, and is able to add something to Burchard's work in that he found anhydrite [6] in abundance at one locality, which, it is believed, gives a clue to the origin of the gypsum. The locality referred to is the Iron Nellie mine, about two miles north of the town of Gypsum.

Gypsum is the principal rock exposed in the vicinity of the mine, but on the mine dump gray massive anhydrite was identified in addition to gypsum. It is recognized by its

[5] Bull. 470, U. S. G. S., p. 120 (1911).
[6] One of the analyses cited by Burchard from a locality east of Gypsum proves the presence of anhydrite. Loc. cit., p. 131.

higher specific gravity (2.86) and by its superior hardness, as well as by optical tests. Thin sections show roughly rectangular subhedra of anhydrite with rectangular cleavage. A little dolomite is present in minute subhedral crystals. The anhydrite has moderate relief, with slight change of relief when the section is revolved. The interference colors are, for the most part, bright second-order colors, ($n\gamma - n\alpha = 0.043$; $n\gamma - n\alpha = 0.038$) but some of the crystals have rather low interference colors of the first order ($n\gamma - n\alpha = 0.005$).

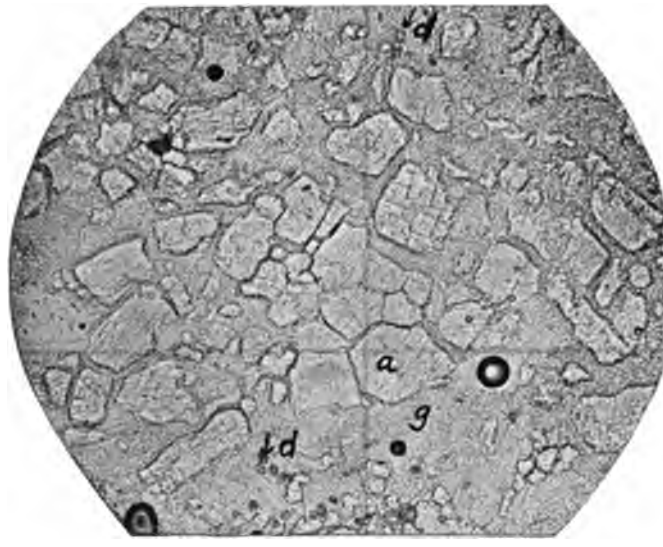


Fig. 4. (x47) Anhydrite from Iron Nellie Mine, Gypsum, Colo.
a, anhydrite; g, gypsum; d, dolomite.

Another specimen, with specific gravity of 2.37, from the dump of the Iron Nellie mine proves to be a mixture of anhydrite and gypsum, as illustrated in Fig. 4. The anhydrite has high relief and the gypsum low relief. Dolomite occurs in minute crystals at the top and the bottom of the photograph.

The gypsum is undoubtedly a hydration product of the anhydrite, and the probability is that all of the gypsum in this region was originally anhydrite. A thin section of massive gypsum, from the road between the Iron Nellie mine and the town of Gypsum, shows (Fig. 10) small interlocking anhedra of gypsum with aggregate structure, which are very

similar to the gypsum areas of Fig. 4. Minute crystals of dolomite are also present. This, like other specimens of rock gypsum of this region, can scarcely be scratched by the finger nail. Microscopic examination shows that the gypsum is made up of minute, intimately interlocking anhedra which may account for the greater hardness. This is an unusual case, for the apparent hardness of aggregates of crystals is usually less than that of single crystals. While the anhydrite was found in association with pyritic ores it probably has no genetic connection with the ore-deposit. As in the Ludwig mine, Lyon county, Nevada, the occurrence of anhydrite with ores is probably a coincidence.

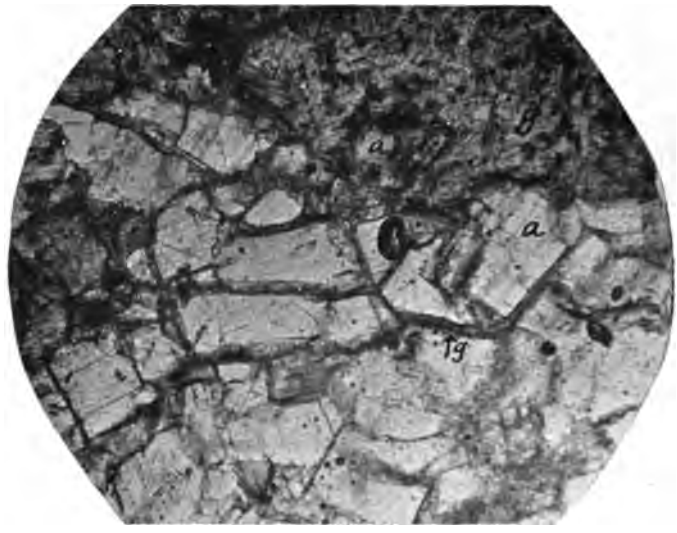


Fig. 5. (x10) Anhydrite—Gypsum Contact, 400-ft. Level. Ludwig Mine, Lyon County, Nev.

LUDWIG, LYON COUNTY, NEVADA.

In 1912 the writer described [7] an extensive deposit of gypsum and anhydrite from the Ludwig mine in Lyon county, Nev. The anhydrite, with a little gypsum, occurs on the 400-ft. level, and on the surface its place is taken by gypsum. A thin section (Fig. 5) of a specimen showing gypsum and anhydrite in contact proves that the gypsum is an alteration product of the anhydrite. Alteration of anhydrite to

[7] Econ. Geol., vol. 7, pp. 185-189.

gypsum for a depth of 400 ft. is unusual. This is a pure white, coarse grained, crystalline anhydrite, with anhedra of about 5 mm. average size, and is quite different from ordinary anhydrite in appearance. It is, in fact, a metamorphic anhydrite, a rock type which has scarcely been recognized before, at least in this country.

In the article above cited, the writer assumed that the anhydrite was originally formed by the evaporation of the remnant of an inland sea. Ransome [8] expressed the opinion that the gypsum was formed by the action of sulphate solutions upon limestone, but in justice to him it should be said that the anhydrite had not been found at the time of his visit. J. C. Jones [9], commenting on the writer's paper, advanced the view that the anhydrite was originally a gypsum bed which had been metamorphosed and dehydrated by the intrusion of grano-diorite dikes. There is, unfortunately, very little available data on the effect of an igneous intrusion on gypsum. Harder [10], speaking of diorite intrusions in gypsum beds in the Palen Mountains, Riverside county, Cal., says, "Apparently, intrusions have had little or no effect on gypsum at the contact, except local pulverizing and probably dehydration." On moderate heating, gypsum passes into a hexagonal or triclinic modification of $CaSO_4$, which is different from anhydrite. This is probably the same as the mineral bassanite found at Vesuvius and described by Zambonini.

One of Jones' arguments is that gypsum occurs interbedded with limestone in the same general region at Lovelocks and at Mound House. In the Mound House deposit, as I shall presently show, gypsum is an alteration product of anhydrite. The absence of salines is also mentioned by Jones as an argument in favor of the derivation of the anhydrite from gypsum, but this argument lacks force, for at a number of localities sedimentary anhydrite occurs without accompanying saline deposits.

The anhydrite at the Ludwig mine was probably formed from an original sedimentary bed of anhydrite. Metamorphism was undoubtedly effective here, but metamorphic crystalline anhydrite could easily have been formed from granular

[8] Bull. 380, U. S. G. S., p. 112 (1909).
[9] Econ. Geol., vol. 7, pp. 400-402 (1912).
[10] Bull. 430, U. S. G. S., p. 412 (1912).

sedimentary anhydrite simply by recrystallization. There is no necessity for appealing to the dehydration of a gypsum bed. As Wallace [11] says, "Direct geological evidence has yet to be adduced before the theory can be accepted that transformation of gypsum to anhydrite at great depths below the surface takes place to such an extent as to be of geological importance."

MOUND HOUSE, LYON COUNTY, NEVADA.

An immense deposit of gypsum at Mound House, Lyon county, Nev., which has been worked for some years, was described by Louderback [12]. Having been informed by Dr. J. C. Jones that anhydrite was identified in drill-cores taken from this deposit, the writer (in August, 1914) spent a day at

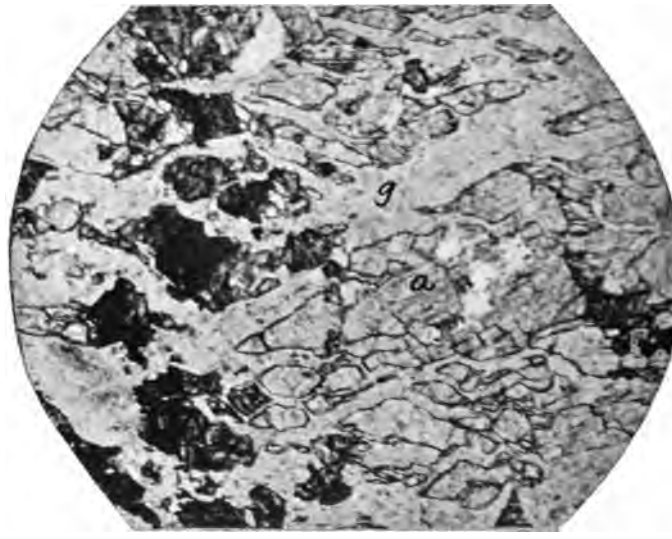


Fig. 6. (x18) Anhydrite from Mound House, Nev.
a, anhydrite; g, gypsum; c, calcite (dark colored).

the Mound House quarry, and found anhydrite in some abundance at certain places on the lowest levels of the main quarry floor, which is at least 100 ft. below the original surface. The anhydrite is a grayish-white, medium-grained (1 to 2 m.m), crystalline anhydrite with specific gravity of 2.75. Gypsum is often present with the anhydrite and the passage of anhydrite

[11] Geol. Mag., (Decade VI), vol. I, p. 276 (1914).
[12] Bull. 223, U. S. G. S., pp. 114-116 (1904).

into gypsum is evident even in some of the hand specimens. Fig. 7 is a photograph of a specimen of banded anhydrite altered on the exterior to gypsum. Thin sections (Fig. 6) show anhydrite (a), gypsum (g), and calcite (c). The formation of gypsum at the expense of anhydrite is unmistakable.

Fig. 7. ($x^{77}/_{100}$) Anhydrite (a) altering to Gypsum (g). Mound House, Nev.

At one place in the quarry a dark colored, somewhat crystalline limestone was found. The thin sections show calcite, tourmaline, phlogopite, gypsum, pyrite, and plagioclase. The significance of the feldspar is not clear, but the occurrence of tourmaline and phlogopite points to high temperature at some stage in the history of the deposit. It seems probable that the Mound House anhydrite, like the Ludwig anhydrite, is a

metamorphic rock. Its rather coarsely crystalline character, the presence of tourmaline and phlogopite, and the occurrence of crystalline limestone in the deposit all point to this conclusion. It has possibly been affected by contact metamorphism, for it is surrounded by diorite, according to Louderback [13], but the metamorphic anhydrite has probably been formed from a sedimentary bed of anhydrite rather than from gypsum.

SHASTA COUNTY, CALIFORNIA.

In 1910 the writer visited the Rising Star mine in Shasta county, Cal., and found both gypsum and anhydrite in close association with the ore deposit. On the 500-ft. (adit) level gypsum occurs between the ore body and the country rock, while on the 1000-ft. level anhydrite occupies the same relative position. The gypsum at this locality is a hydration product of anhydrite, as was proved by Graton [14].

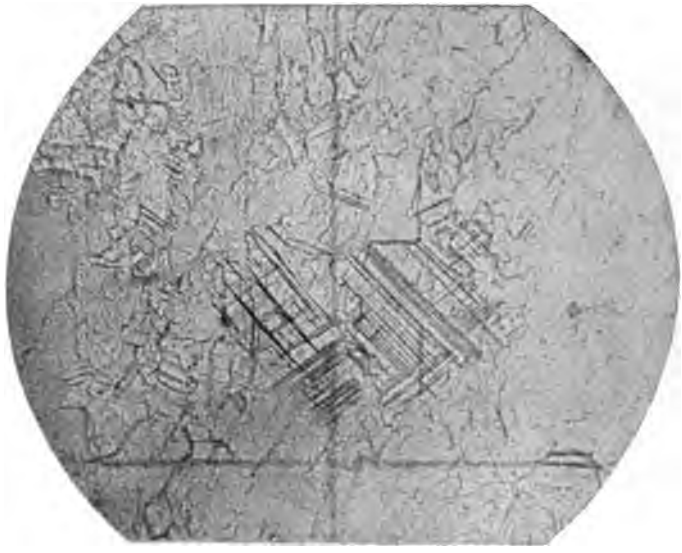


Fig. 8. (x80) Anhydrite with Twin-lamellae, Rising Star Mine, Shasta Co., Cal.

The anhydrite is a finely granular, gray, slightly schistose rock, and sometimes contains chlorite, sericite, and pyrite. In

[13]Loc. cit.
[14]Bull. 430, U. S. G. S., p. 100 (1909).

a few specimens it is intimately associated with sphalerite. A beautiful, colorless to slightly rose-gray tinted, alabaster-like anhydrite also occurs here. In thin sections polysynthetic twin-lamellae diagonal to the cleavage cracks and parallel to (101) are prominent (Fig. 8). The anhydrite was probably formed from hydrothermal solutions at a moderate temperature, as indicated by the presence of chlorite. Boyle [15], who described the Bully Hill and Rising Star mines, considers that the relation of gypsum to the anhydrite is not settled, but the thin sections prove conclusively that the gypsum on the upper levels was produced by the hydration of anhydrite.

CHAPULTEPEC, ALABAMA.

A small specimen from this locality, obtained from a mineral dealer, shows pale blue anhydrite associated with white gypsum. The thin section (Fig. 9) shows conclusively that

Fig. 9. (x15) Anhydrite (a), Gypsum (g), Chapultepec, Ala.

the gypsum was formed directly from the anhydrite. The sharp line of demarcation (Fig. 9) between the two minerals is striking. Nothing further is known about this specimen, except that it is said to be from a limestone quarry.

[15]Bull. 85, A. I. M. E., p. 103, (Jan., 1914).

Occurrences of Anhydrite in the United States.

The following list is a summary of the recorded occurrences of anhydrite, arranged in alphabetical order of states.

Alabama.—Chapultepec (see above).

California.—Palen Mts., Riverside county. Anhydrite is interlayered with crystalline gypsum in beds alternating with layers of limestone. The gypsum and anhydrite are thought to be due to original differences in composition.

Shasta county (See above).

In Orange county, near Anaheim, white, translucent, semi-crystalline anhydrite was found. Hanks, *Fourth Ann. Report,* State Mineralogist of California, p. 72 (1884).

At Searles Borax Lake in San Bernardino county, anhydrite was found with borax, colemanite, trona, halite, gypsum, hanksite, dolomite, and other minerals. Hanks, *Amer. Jour. Sci.,* vol. 37, p. 66 (1889).

Anhydrite has been reported from the St. Ignacio and Cerro Gordo mines in Inyo county, and from the Mammoth mine in Mono county. Eakle, *Bull.* 67, California State Mining Bureau, p. 181 (1914).

Colorado.—Eagle county. (See above).

Connecticut.—Meriden. Graton says that Palache found anhydrite intergrown with prehnite and datolite in trap. *Bull.* 85, A. I. M. E., p. 1393 (Jan., 1914.)

Iowa.—Centerville, Appanoose county. At this locality a 5-ft. bed of compact anhydrite underlain by 5 ft. of crystalline gypsum was encountered in a drill hole at a depth of 542 ft. The anhydrite was identified by chemical analyses. Kay, *Bull.* 580-E, U. S. G. S., pp. 59-64 (1914).

Kansas.—Kingman, Kingman county. Willard, reported by Bailey and Failyer. *Trans.* Kans. Acad. Sci., vol. 13, p. 78 (1891-2).

Kanopolis, Ellsworth county, and Lyons, Rice county. Rogers, *Amer. Jour. Sci.,* vol. 29, pp. 258-261 (1910); also this paper, above.

Louisiana.—At Grande Cote (Weeks Island) anhydrite occurs as vertical dark streaks in "white sand". Harris, *Bull.* 7, Louisiana Geol. Surv., p. 7 (1907).

Near Vinton, Calcasieu Parish, 16 ft. of anhydrite occurs at a depth of 1000 ft. (*Ibid,* p. 38).

At Petite Anse (Avery's Island) the salt contains 2.16% of insoluble matter, which is anhydrite. (*Ibid,* p. 16).

At Belle Isle anhydrite was found at various depths in the Knapp well No. 1. Harris, *Bull.* 429, U. S. G. S., p. 45 (1910).

Massachusetts.—Northampton. Anhydrite occurs with calcite and pyrite in cavities of trap in Larrabee's quarry. Emerson, *Bull.* 126, U. S. G. S., p. 26 (1895).

Michigan.—At Mt. Pleasant anhydrite was found in a deep well at various depths from 1225 to 1373 ft. Grimsley, Mich., Geol. Surv., vol. 9, p. 90 (1904).

In Berrien county, at the Niles well a 20-ft. bed of anhydrite and gypsum was found at 615 to 720 ft. (*Ibid,* p. 97).

Anhydrite occurs in the Benton Harbor well at 815 ft., in the Kalamazoo well at 1500 ft., in the Manistee well at about 1800 ft., in the Marine City well at 1400 ft., in the Mt. Clement well at 980 ft., and in the Muskegon well at 2350 ft. (*Ibid,* p. 97).

Lane believes that all the calcium sulfate in the Michigan wells is present in the form of anhydrite rather than gypsum, (*Ibid,* p. 84, footnote).

Kalamazoo. Anhydrite was found with dolomite in a well at depths of 1490 to 1530 and 1570 to 1730 ft. Lane, Mich. Geol. Surv., *Annual report* for 1908, p. 59.

Mt. Pleasant. Anhydrite was found in a 45-ft bed at the depth of 200 ft. and anhydrite with gypsum occurred above and below this bed. (*Ibid,* p. 83).

Grand Lake, near Alpena. A 28-ft. bed of anhydrite was found in well No. 1 of the Alpena Land Co., at a depth of 1437 ft.; salt and anhydrite at 1552 ft. and 1589 ft.; and anhydrite and dolomite at depths of 1533 and 1701 ft. (*Ibid,* p. 93).

Ecorse. Anhydrite with dolomite is abundant in the Morton Salt Co.'s well from 565 ft. to 637 ft., at 922 ft., and at 962 ft. At 942 ft., anhydrite occurs with salt and at 1062 ft. a 5-ft. bed of almost solid anhydrite occurs. (*Ibid,* pp. 97-99).

Milan. Anhydrite occurs at depths of 1025 to 1100 ft., and a depth of 1210 to 1300 ft. (*Ibid,* p. 64).

Oakwood, South Detroit. Anhydrite is reported from a salt shaft at this locality. Sanford and Stone, *Bull.* 585, U. S. G. S., p. 97 (1914).

Missouri.—At St. Louis anhydrite in sky-blue, radiated, fibrous aggregations was found in cavities in limestone. Leonhard, *Trans.* St. Louis Acad. Sci., vol. 4, p. 448 (1882).

In Franklin county, anhydrite was found in light pink, radiating columnar aggregations. Leonhard, *Ibid,* p. 449.

Montana.—In Dawson county, 14 miles west of Wibaux, anhydrite crystals are found in a "gumbo" clay beneath a scoriaceous volcanic rock which caps a butte. The anhydrite has been formed from gypsum by the heat of the overlying lava, and the transition is beautifully shown. Rowe, *Amer. Geol.,* vol. 35, p. 106 (1905). (Prof. Rowe has recently written me that this mineral is alabaster and not anhydrite.)

Nevada.—Ludwig, (See above).

Mound House. (See above).

New Jersey.—At West Paterson, pale blue, transparent anhydrite associated with amethystine quartz was found in basalt. Thaumasite is an alteration product of the anhydrite. Allen, *Amer. Jour. Sci.,* vol. 39, p. 134 (Jan., 1915).

New Mexico.—In the foot hills of the White Mountains, massive anhydrite occurs in beds up to 35 ft. thick with limestone and gypsum. Herrick, *Bull.* 223, U. S. G. S., p. 90 (1904).

At the western base of Nacimiento Mountains a 40-ft. bed of anhydrite and gypsum occurs. *Ibid,* p. 94.

East of the Sandia Mountains an exposure of gypsum and anhydrite occurs. *Ibid,* p. 95.

East of Socorro, gypsum and anhydrite occur. *Ibid,* p. 96.

In the Quelites grant, valley of the San Jose, massive anhydrite occurs in beds over 50 ft. thick. *Ibid,* p. 97.

On the Rio Salado massive beds of anhydrite occur. *Ibid,* p. 97.

New York.—At Lockport, blue anhydrite occurs in geodes of limestone with calcite and gypsum. Dana, "System of Mineralogy," 6th ed., 1892.

Staten Island. Massive anhydrite occurs in serpentine with talc and brucite. Whitlock. *Bull.* 70, N. Y. State Museum Report, p. 72 (1903).

Ohio.—At Newbury, near Cleveland, in a deep well a 15-ft. bed of anhydrite was found at a depth of 2154 ft. and a 40-ft. bed of anhydrite at a depth of 2300 ft., below rock salt in each case. Orton, Ohio Geol. Surv., vol. 6, p. 353 (1888).

Oklahoma.—On Salt Creek and Bitter Creek in the northwestern part of Oklahoma the lower half (8 to 10 ft.) of a gypsum bed is anhydrite, locally called "Salt Creek marble". Gould. *Bull.* 1, Okla. Geol. Surv., p. 30 (1908).

Near Chimney Butte, Woodward county, boulders of anhydrite up to 5 ft. in diameter occur at about the middle of a gypsum layer. Snider, *Bull.* 11, Okla. Geol. Surv., p. 142, (1913).

In Major county, thick short lenses of anhydrite occur in the the Medicine Lodge gypsum. *Ibid,* p. 155.

In Blaine county, large blocks of anhydrite occur at the top of many of the bluffs. *Ibid,* p. 155.

In a cañon in Blaine county, a 3-ft. bed of anhydrite occurs between gypsum layers. *Ibid,* p. 156.

At Wilson, Blaine county, in the quarry of the Oklahoma Gypsum Co., the anhydrite member of the Medicine Lodge gypsum is about 3 ft. thick and has 10 ft. of pure white gypsum above it. *Ibid,* p. 156.

Near Southard, Blaine county, 4 ft. of anhydrite occurs at the top of the hill. *Ibid,* p. 157.

Four miles west of Ferguson, Blaine county, the Medicine Lodge gypsum contains a 9-in layer of anhydrite. *Ibid,* p. 158.

Near Bickford, Blaine county, the Medicine Lodge gypsum is made up of a 2-ft. layer of anhydrite between a 6-ft. and a 9-ft. layer of gypsum. *Ibid,* p. 159.

Pennsylvania.—At the Darby tunnel on the B. & O. R.R., near Philadelphia, violet-red anhydrite occurs as a crust on diabase. *König. Zeit. fur Kryst. u. Min.*, vol. 17, p. 88 (1890).

Tennessee.—Near Nashville, in cavities in limestone, pale blue, bladed aggregates of anhydrite occur with calcite. Dana mentions this locality and the writer also has specimens from there.

Texas.—At Spur, Dickens county, anhydrite occurs in abundance in a deep well which was bored for water to a depth of 4489 ft. Anhydrite is first found at 298 ft. and occurs at intervals down to 4105 ft. The anhydrite occurs in beds ranging from a few feet up to a maximum of 73 ft. in thickness. The anhydrite is intimately associated with dolomite. It is partly original and partly secondary. Udden believes that the anhydrite has been formed in connection with the dolomitization of limestone by a reaction between magnesium

sulfate and calcium carbonate. Udden, *Bull.* Univ. Texas, No. 363, (Science Series No. 28) pp. 1-90 (Oct., 1914).

Utah.—Nephi. Analyses of specimens from this locality prove that the gypsum contains about 22 % of anhydrite. Boutwell, *Bull.* 223, U. S. G. S., p. 106 (1904).

At the Cactus mine, Beaver county, anhydrite occurs as a gangue mineral. Lindgren, *Econ. Geol.*, vol. 5, p. 522 (1910). Butler, *Prof. Paper* No. 80, U. S., G. S., pp. 106, 123, plates XIII, XIVA (1913).

In Sevier county, anhydrite occurs with halite (A. F. R.).

Virginia.—At Plasterco, two miles southwest of Saltville, much anhydrite is admixed with the gypsum and the two gradually grade into each other without any degree of regularity. The anhydrite is identified by a chemical analysis. Watson. "Mineral Resources of Virginia", pt. 7, p. 333 (1907).

Near Saltville, numerous small anhydrite crystals were found scattered through gypsum. Stose, *Bull.* 530, U. S. G. S., p. 246 (1911).

Modes of Occurrence of Anhydrite.

1. As a sedimentary rock, often associated with salt in inland sea deposits. Central Kansas, Michigan, Oklahoma, Colorado, etc.

2. As a vein mineral or an associate of ores. Beaver county, Utah; Shasta county, California.

3. As the metamorphic equivalent of sedimentary anhydrite. Ludwig mine, Lyon county, Nevada; Mound House, Nevada.

4. As a cavity filling in igneous rocks. Northampton, Mass.; West Paterson, N. J.

5. As a cavity filling in limestones. Nashville, Tenn.; Lockport, N. Y.; St. Louis, Mo.

6. As a replacement of limestone along with dolomite. Spur, Dickens county, Texas.

7. As the dehydration product of gypsum. Sulz-am-Neckar, Germany.

USES OF ANHYDRITE.

1. As land plaster.
2. As a building and ornamental stone.
3. As estrich or floor plaster.

Only the last-mentioned use is of possible importance [16].

RELATION OF GYPSUM AND ANHYDRITE.

Gypsum is usually associated with anhydrite. It is mentioned at about two-thirds of the localities given in the preceding list. As regards the relations between these two minerals, there are three possibilities to consider. Either they are contemporaneous, or gypsum is derived from anhydrite, or *vice versa*. At Gypsumville, Manitoba, Wallace [17] believes that gypsum and anhydrite are contemporaneous. Snider [18] is also of the opinion that gypsum and anhydrite in the Oklahoma occurrences are the result of original deposition. While the absence of microscopic data renders the opinions of Wallace and Snider somewhat doubtful, the experiments of van't Hoff and his associates furnish an explanation of the original deposition of gypsum and anhydrite. Whether gypsum or anhydrite forms depends upon the temperature and the salinity of solutions. Variations in these conditions might produce both gypsum and anhydrite in the same series of beds.

As to the production of anhydrite by the dehydration of gypsum not much evidence is available. Only one undoubted case of the transformation of gypsum into anhydrite is on record. G. Rose [19] at Sulz-am-Neckar, Germany, found anhydrite pseudomorphous after gypsum. Hoppe-Seyler produced anhydrite from gypsum by heating it in a saturated sodium chloride solution at 125 to 130° C. Rowe [20] describes anhydrite in the form of gypsum crystals produced by the heat of overlying lava in Dawson county, Montana. There is no proof that the mineral is anhydrite; in fact, as above stated, it is now recognized as alabaster. In a similar case at Vesuvius the calcium sulphate is not anhydrite, but a modification called bassanite.

[16] Glasenapp, Tonindustrie Zeitung vol. 33, pp. 749-751 (1909).
[17] Amer. Geol., vol. 33, p. 106 (1905).
[18] Geol. Mag. (Decade VI), vol. I, p. 276 (1914).
[19] Okla. Geol. Surv., Bull. 11, p. 15 (1913).
[20] Pogg. Ann., vol. 145, p. 194 (1872).

It will be noticed that most of the prominent occurrences of anhydrite are those of deep wells and mines. While anhydrite often occurs in sedimentary beds it rarely occurs on the surface. On the surface its place is usually taken by gypsum. The Oklahoma and New Mexico occurrences are probably the only striking exceptions to this rule in this country.

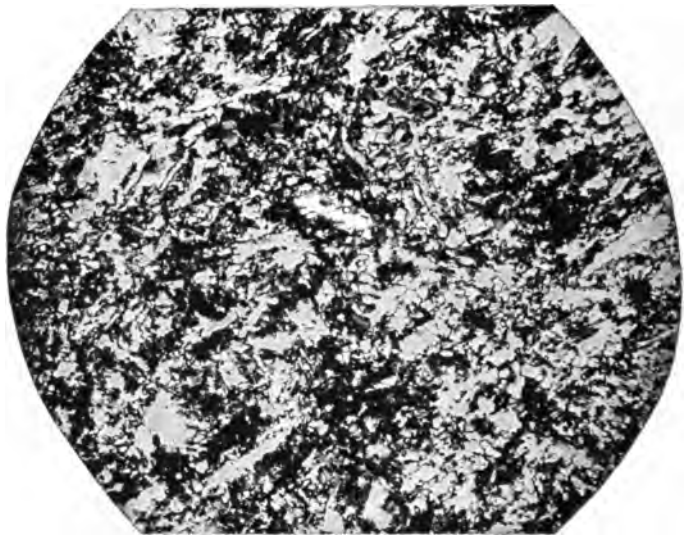


Fig. 10. (x40) Gypsum from Gypsum, Colo. (Crossed nicols).

A study of thin sections of the gypsum from six different localities in the United States conclusively proves the formation of gypsum by the hydration of anhydrite at these localities. Besides the direct proof mentioned, the microscopic structure of the gypsum furnishes additional evidence. The gypsum areas of Figs. 3, 4, and 8, examined with crossed nicols, show intricate interlocking anhedra similar to Fig. 10, which is a microphotograph of gypsum from near the Iron Nellie mine, Eagle county, Colorado. This gypsum has been produced by the hydration of anhydrite. The structure of closely knit anhedra with suture-like boundaries is probably produced by the increase of volume on passing from anhydrite to gypsum.

Fig. 11 [21] is a microphotograph of gypsum from near King

[21]The twin lamellae in left center of photograph are due to heating when slide was mounted.

City, Monterey county, Cal.[22]. This gypsum is probably formed directly by evaporation of an inland lake. The structure is much like that described by Lacroix [23] from the Paris basin at Montmartre.

Fig. 11. (x35) Gypsum from King City, Monterey County, Cal., (Crossed nicols).

Fig. 11 is quite distinct from Fig. 10. This difference in microscopic structure may be of service in determining the origin of a given gypsum deposit. The principal difficulty is that gysum is easily recrystallized, even when originally formed from anhydrite. This has evidently been the history of some of the gypsum at the Rising Star mine in Shasta county, Cal., at the Ludwig mine in Lyon county, Nev., and at the Mound House deposit in Nevada. The microscopic structure of the recrystallized gypsum is different from both Figs. 10 and 11.

From all the available evidence it seems certain that many, if not most, of the gypsum beds have been formed by the hydration of sedimentary anhydrite.

[22]This is probably from the Bitterwater Valley deposit mentioned by Fairbanks. Bull 223, U. S. G. S., p. 120 (1904).

[23]Nouvelles Archives du Muséum. (3) vol. 9, plate 10, fig. 2.

SUMMARY.

Anhydrite is a fairly common and widely distributed mineral in the United States.

Anhydrite is easily mistaken for limestone or gypsum, but may be distinguished from these by careful microscopic, solubility, and specific gravity tests, as well as by quantitative chemical analyses.

The common occurrence of anhydrite is in sedimentary beds, which on the surface have changed to gypsum. Many beds of gypsum have thus been formed.

The sedimentary anhydrite may be metamorphosed to coarsely crystalline anhydrite, as at Ludwig, Nev., and Mound House, Nev. This anhydrite constitutes a metamorphic rock.

Stanford University, Cal.,
March, 1915.

STEEL SHAFT TIMBERING AT LOS OCOTES MINE

BY R. H. CROMWELL.*

The Los Ocotes copper mine in the State of Oaxaca, Mexico, had been developed over a period of a number of years principally by the San Juan shaft. This shaft started as a small prospect working on the vein. It was more or less crooked and irregular in cross-section, but as the ore was found to continue in depth it had been sunk intermittently in preference to starting a new and more elaborate shaft.

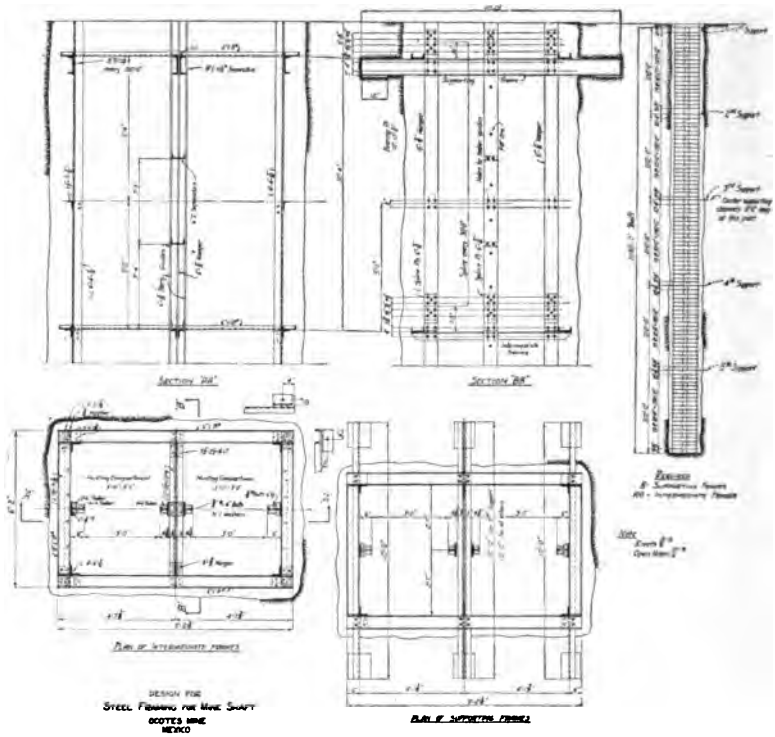
When 600 ft. in depth had been reached it was decided to sink 200 ft. deeper and then equip the shaft for regular extraction of the ore developed. From the 600- to the 800-ft. level the shaft was sunk two-compartment size. It was carefully plumbed from the surface, and the sinking was carried on in such manner that the cross-section of the shaft from the 600- to the 800-ft. level would square up with the proposed enlarged and straightened cross-section of the shaft from the surface to the 600-ft level. The rock was quite solid, lagging being required in only a few places.

Timber in this shaft rots very quickly, even when protected with coal tar; timber sets could not be relied upon to last more than three years. A considerable body of ore had been developed, and it was therefore assumed that the shaft would be used for a number of years. For these reasons it was decided to equip it with a steel gallows frame and steel timbering.

In enlarging and straightening the shaft from the surface to the 600-ft. level, it was found most advantageous to work from the surface downwards. A heavy swinging wooden platform, or "balsa," about the size of the finished cross-section of the shaft was constructed, and was used for supporting the men engaged in carrying down the enlarging benches in the shaft. This platform was swung from four cables attached to its corners and joining in a central single cable operated by a small hoist on the surface. Before a round of holes was fired the platform could therefore be raised and quickly lowered into place again after the blasting. This saved a good deal

*E. M., Columbia, 1902. Engineer for Tezuitlan Copper Co., 82 Beaver St., New York.

of time and at the same time protected the steel timbers. As ventilation in this shaft was excellent, after a round of holes was fired, but little time was lost in lowering the "balsa" and getting a new round of holes started. As the trimming and



enlarging of the shaft proceeded downwards, bulkheads were put in successively at the different levels below the point where trimming was going on. From these bulkheads the material blasted from the shaft was removed currently and stored in the different levels, from where it could be economically hoisted when the steel gallows frame and shaft timbering was complete.

We first attempted to use air-hammer drills mounted on light columns for the trimming and enlarging of the shaft, but it was found that the natives lost too much time in preparing setups and making connections. Better progress could be made by hand drilling, as in some cases only short holes were required. About 6 ft. of shaft was trimmed per round. The men would shoot whenever a round of holes had been

completed. Plumb bobs from the four corners of the collar of the shaft were lowered to the trimming bench after each round of holes was fired, the position of the new holes being determined by the plumb bobs. During trimming operations, water was being removed from the bottom of the shaft by a small Cameron pump driven by compressed air. Before blasting lengths of both water column and air pipes were removed at the point in the shaft where the round of holes was to be fired. After these holes were blasted and the loose ground barred down, the pipes were replaced and pumping resumed.

The steel timbering, shown in the drawing, was put in as fast as the trimming of the shaft progressed. The ends of the flat 6x⅜-in. hangers, to which the sets were bolted, were maintained at sufficient distance from the trimming bench in the shaft so that blasting could not injure the steel timbers. They were also protected by the "balsa" which, before each blast, was always raised from the bench to the bottom of the steel hangers.

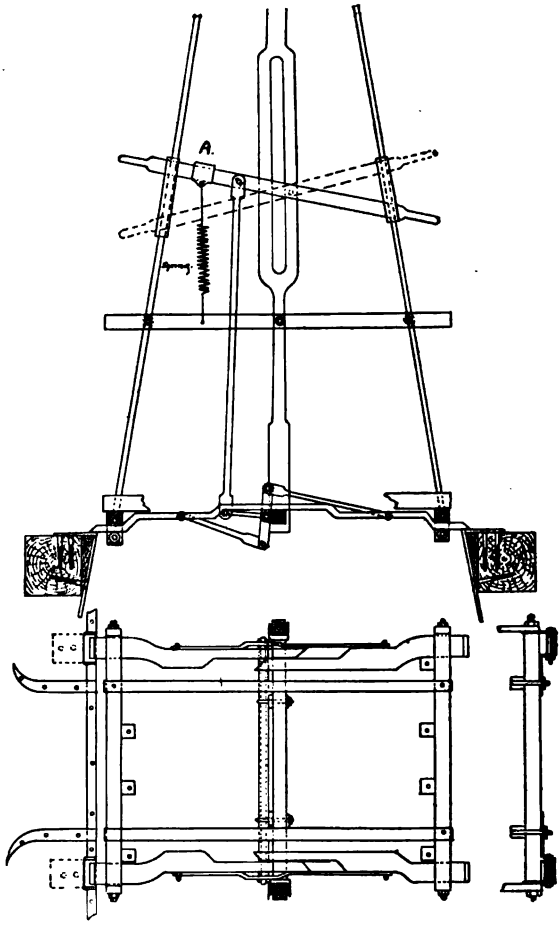
The drawing shows supporting sets of 8-in. steel channels which were cemented into steps and into the sides of the shaft. These supporting sets, from which the steel timbering hung until securely wedged to the sides of the shaft with blocking, were installed just below the collar and at 210 ft. intervals in the shaft.

All the steel, before being installed, was painted with a mixture of coal tar and turpentine. The steel went together rapidly and without difficulty, and after each set was blocked up the whole structure was very rigid. From the surface to the 600-ft. level, sets were put in 10 ft. apart. From the 600- to the 800-ft. level, as the ground showed a tendency to cave, sets were put in every 5 ft. and lagged with 2-in. planks laid lengthwise between the sets.

For the timbering of this shaft, about 73 tons of steel was required, costing approximately $100 U. S. currency per ton, laid down at Los Ocotes mine. The steel gallows frame contained 15 tons of steel, which cost about $140 per ton laid down at the mine.

In connection with the equipment of the shaft at this mine it was planned to use chairs attached to and operated from the cages. Referring to the sketch of this arrangement, a weight or spring at A automatically withdraws the chairs

when the cage is raised and its weight taken from them. The arrangement was devised by John Martin of Tariche, Oaxaca, and has proved very satisfactory at the San Juan



AUTOMATIC CHAIRS FOR MINE CAGE

mine of that place. It has the advantage of avoiding the expense and danger of having sets of chairs at each of the levels from which hoisting is being carried on. In operating the automatic cage chairs, the cage man holds the lever against the action of the weight and spring until the protruding chairs rest upon the landing and are held in that position by the weight of the cage.

CONSTRUCTION AND MAINTENANCE OF NEW YORK STATE HIGHWAYS*

BY ARTHUR H. BLANCHARD.†

During 1913 and 1914, Mr. Prevost Hubbard, chemical engineer in charge of the division of roads and pavements of the Institute of Industrial Research, Washington, and the writer served as members of the advisory board on highways of the New York State Department of Efficiency and Economy. Various problems, relative to the organization, administration, specifications, construction and maintenance of highways, and related activities of the New York State Highway Department, were referred to this board, from time to time during the two years it was in office, by the Commissioner of Efficiency and Economy, the Hon. John H. Delaney. At the request of the Commissioner, the board collated its numerous reports, and presented the final report referred to in the title of this article. The following resumé will deal primarily with problems of interest to engineers of construction, and contractors. All recommendations embodied in the report were the result of exhaustive investigations of the headquarters office in Albany, and nine division offices of the division engineers, and the design, construction and maintenance of highways throughout the State.

Organization.—The important recommendations as to the organization of the New York State Highway Department are as follows:

That the Commissioner of Highways shall be a civil engineer having had responsible charge of the construction and maintenance of highways for at least five years, and being a full member or having fulfilled the requirements for the grade of full member of the American Society of Civil Engineers (M. Am. Soc. C. E.).

That the Commissioner of Highways shall appoint three deputy engineers and twelve division engineers, each of whom shall be a civil engineer who has had responsible charge of the construction and maintenance of highways for at least three years and is a full member or has fulfilled the requirements for the grade of full member of the American Society of Civil Engineers. Each of the deputies shall have charge, under the direction of the Commissioner of Highways, of all work in four divisions. The division engineers will report, in the organization recom-

*A review of the 1915 report of the advisory board on highways to the New York State Department of Efficiency and Economy.

†Professor of Highway Engineering, Columbia University, and consulting highway engineer, New York City.

mended, to one of the deputy engineers. In each division there shall be engineers in charge of counties reporting to the division engineer. Each division engineer shall in his division and each county engineer shall in his county have charge of the construction and maintenance of all state and county highways and all state work relating to town highways and bridges.

Comprehensive Advertisements Necessary to Secure Competition in Bidding.—A very general criticism may be made regarding the method of advertising contracts by the Highway Commission, which has invariably resulted in giving incomplete information to prospective bidders, and, in certain cases, misleading information. It is well known that the object of advertisements is to secure as comprehensive competition as practicable from responsible contractors, hence it follows that the information conveyed in advertisements should be such as not only to attract the attention of such bidders, but also give them such information as will enable them to decide whether or not it will be worth their while to submit bids. Concise advertisements containing the character of information referred to above in many cases saves considerable correspondence and tends to reduce the process of submitting bids to the most economical and efficient basis from the standpoints of all interested parties. The essential data to be included in advertisements of highway work in New York could be arranged in the form of a table with the following headings: Road number, division, county, town, name of highway, approximate length in miles, square yards of road or pavement, class of work, guarantee, date of completion.

Preliminary Investigations Necessary to Determine Suitable Types of Road and Pavements.—Because of the following reasons the design of many state and county highways in New York State during 1913 and 1914 has been both inefficient and uneconomical.

First, the comparatively infinitesimal amount of investigation which has been considered necessary as preliminary to the design of a given highway;

Second, failure to utilize readily available data, such as traffic censi, statistics relative to motor traffic registration in incorporated villages and cities, routes of motorbuses at present operated, population statistics and data of a similar nature;

Third, failure to compile and make accessible for reference all important details which constitute the history of highways constructed;

Fourth, the general meagreness of detailed knowledge of the many different materials on the market, and the varied methods in connection with which they may be used;

Fifth, belief by many highway officials and engineers in a panacea for the treatment of all classes of highways;

Sixth, a confusion of ideas on the part of many of the officials and engineers of the Highway Department as to the reasons for the success or failure of a given type or road or pavement;

Seventh, non-observance of the relationship between the adaptability of various methods and materials, the variability in the cost of labor and materials, and the accessibility of new materials and machines;

Eighth, low ideals possessed by many of the engineers of the Highway Department as to the character of work which should be secured, which has resulted from past acceptance of inferior work and from lack of opportunity to become familiar with work of high grade in different parts of the state and other localities.

Width of Roadway.—In view of the fact that the unit width of traffic lines should be considered as 9 or 10 ft., and because the important trunk highways of New York are subjected to a rapidly developing traffic of motor trucks and motorbuses, it was recommended that the Commissioner of Highways should be given authority to construct many of the trunk highways with improved roadway surfaces of 20 ft. in width instead of being limited to a maximum width of 16 ft.

Specifications.—Early in its work in 1913 the board was directed to review the contracts and specifications of several lettings. As indicating the pitfalls which may prevail in specifications, the reasons for the recommendations to cancel many contracts are herewith cited: (1) Materials specified distinctly different in type and grade from those advertised; (2) specifications which unnecessarily limited competition; (3) monopolistic specifications substituted for more open specifications which were indicated in the advertisement; (4) acceptance by the Highway Commission of bids on material other than specified; (5) bids requested on certain items which were so indefinite that an intelligent bid could not be made without knowledge obtained from the Highway Department; (6) conflicting requirements in different parts of the same specifications; (7) different specifications for the same contract submitted to various bidders; (8) acceptance by the Highway Commmission of altered bids; (9) duplication of work covered by different items upon which separate bids were requested; (10) inherently faulty specifications.

The revelation of the defects in the specifications resulted in a weeding out of certain inefficient employees of the Highway Department, the inauguration of more rigid supervision

fied specifications, and finally an appreciation by the Highway Commission that the writing of an entirely new set of specification was imperative if contractors were to be fairly treated and the interests of the State conserved.

During 1913 and 1914 the board was requested to draft specifications for types of pavements suitable for use on state and county highways and to submit criticisms of specifications in current use by the Highway Department. The board, recognizing the rapid increase in all classes of traffic on state and county highways, and that the funds to be used were derived from the sale of fifty-year bonds, recommended the use of cement concrete foundations for the four types of pavements to be used on properly designated state and county highways. Under the conditions existing in New York State in 1913, the board recommended the use of the following types of pavements for the highways noted: Bituminous concrete pavement with an aggregate of broken stone ranging from ⅛ to 1¼ in. in dimensions; Topeka bituminous concrete pavement; brick pavement; and stone block pavement.

During the drafting of new specifications for the Highway Department, considerable discussion occurred pertaining to the relative merits of alternate-type specifications and blanket specifications for bituminous materials. Although the chemists of the Highway Department recognized the value of separate specifications for refined coal tar and refined water-gas tar, they were averse to the use of separate specifications covering the various types of asphalts secured from various sources and manufactured by several different processes. The board pointed out that the individual tests requried for specifications for individual materials may serve one or more of the following purposes: (1) they may directly indicate the suitability for a given use of the material specified; (2) they may serve as a means of identifying the source of a material or even the material itself; (3) they may serve to control uniformity in the preparation or manufacture of a material. It seemed apparent to the board that tests used in selecting or specifying a material for a given use are most efficient when the test limits adopted specifically define a material, and when such material has previously proved satisfactory for a particular purpose. It seems evident that the narrow test limits per-

mitted in alternate-type specifications allow the fulfillment of the essential requisites of specifications for bituminous materials in the most efficient manner.

Construction.—New York State built during 1913 and 1914 many miles of bituminous pavements constructed by the penertation method. The surfaces of many of these pavements showed waves or ruts soon after being opened to traffic The board believes that one of the inherent causes of these conditions is the light rolling required prior to the application of bituminous material. The usual method of rolling consisted in shaping up the broken stone course by one passage of the roller over the surface. It is impossbile to secure inherent stability unless the broken stones of the course are thoroughly compacted and keyed together prior to the application of the bituminous material. During 1913 and 1914 many bituminous pavements of this type were poorly constructed, due to inefficient distribution of the bituminous material. The Highway Department specifications required the use of an approved distributor. Contractors, however, found it impracticable to secure a description of an "improved distributor". The board, therefore, submitted the following specification:

> The pressure distributor employed shall be so designed and operated as to distribute the asphalt cement or refined tar specified uniformly under a pressure of not less than 20 lb. nor more than 75 lb. per sq. in. in the amount and between the limits of temperature specified. It shall be supplied with an accurate stationary thermometer in the tank containing the asphalt cement or refined tar and with an accurate pressure gauge so located as to be easily observed by the engineer while walking beside the distributor. It shall be so operated that, at the termination of each run, the asphalt cement or refined tar will be at once shut off. It shall be so designed that the normal width of application shall be not less than 6 ft. and so that it will be possible on either side of the machine to apply widths of not more than 2 ft. The distributor shall be provided with wheels having tires each of which shall not be less than 18 in. in width, the allowed maximum pressure per square inch of tire being dependent upon the following relationship between the aforesaid pressure and the diameter of the wheel; for a 2-ft. diameter wheel, 250 lb. shall be the maximum pressure per linear inch of width of tire per wheel, an additional pressure of 20 lb. per inch being allowed for each additional 3 in. in diameter.

Inspection.—Especially during 1913, poor results, due to inefficient inspection were apparent on every hand. Inspectors without previous training on the class of work of which they had responsible charge were employed in many instances. The 1913-1914 highway law was in part responsible for this condi-

tion, as it required that inspectors of construction should be residents of the county in which the highway to be constructed was located. Such resident qualifications serve no useful purpose and tend to handicap efficient and economical work.

Maintenance.—Among the several details of maintenance of state and county highways which were covered in the report may be mentioned the opinions of the board relative to the use of "cold oil" and "hot oil" for surface treatments. Based on the conditions of use in New York, it was the conclusion of the board that such products, when used in the manner described, were not suitable for economical maintenance and repair, for the following reasons: (1) Oils which meet these specifications require considerable time in which to set up, when used in the manner specified; (2) all petroleum products. while in a fluid state, act to a certain extent as lubricants, when used as specified; (3) it is therefore evident that more or less movement of the road surface will take place under traffic during the setting-up period; (4) the bituminous mats or carpets formed invariably become wavy and full of humps and ruts under heavy traffic; (5) due to the character of the resulting surface, further maintenance is rendered difficult and costly; (6) prior to retreatment of roads thus repaired, it is often necessary to remove considerable portions of the bituminous mats with picks and shovels or with scarifiers.

Regulation of Motor Truck and Motorbus Traffic.—During the board's investigations, in 1913 and 1914, of the use of the state and county highways by various classes of traffic, the board became convinced that the laws of the State of New York do not adequately cover the regulation of motorbus and motor-truck traffic, nor does the board believe that proper cognizance is taken of the development of the above classes of traffic in connection with the design of the highways of the State. It is evident that a consideration of motorbus and motor-truck traffic, due to strains produced by heavy loads being carried over the highways at speeds of up to 30 miles an hour, will materially influence the selection of the type of pavement, the character of the foundation to be used and the determination of the requisite width of improved surface. It was found in 1914 that over 16,000 motor trucks had been registered by

the Secretary of State, and that over 100 motorbus routes were in operation throughout every part of the State, and primarily operated on state and county highways. According to the records, the motorbuses carried from 5 to 40 passengers, had a horse power rating of from 20 to 75, and weighed loaded from 1½ to 8 tons. It is of interest also to note that the overall width of many of these buses was 90 in. or more. The board included in its report definite traffic regulations for the protection of the state highways, which covered loads, tire widths, speeds, etc., for horse-drawn vehicles, motor cars, motor trucks, motorbuses and traction engines.

PETROLOGY AND ECONOMIC GEOLOGY OF THE SKYKOMISH BASIN, WASHINGTON*

BY WARREN S. SMITH, B.S., A.M.

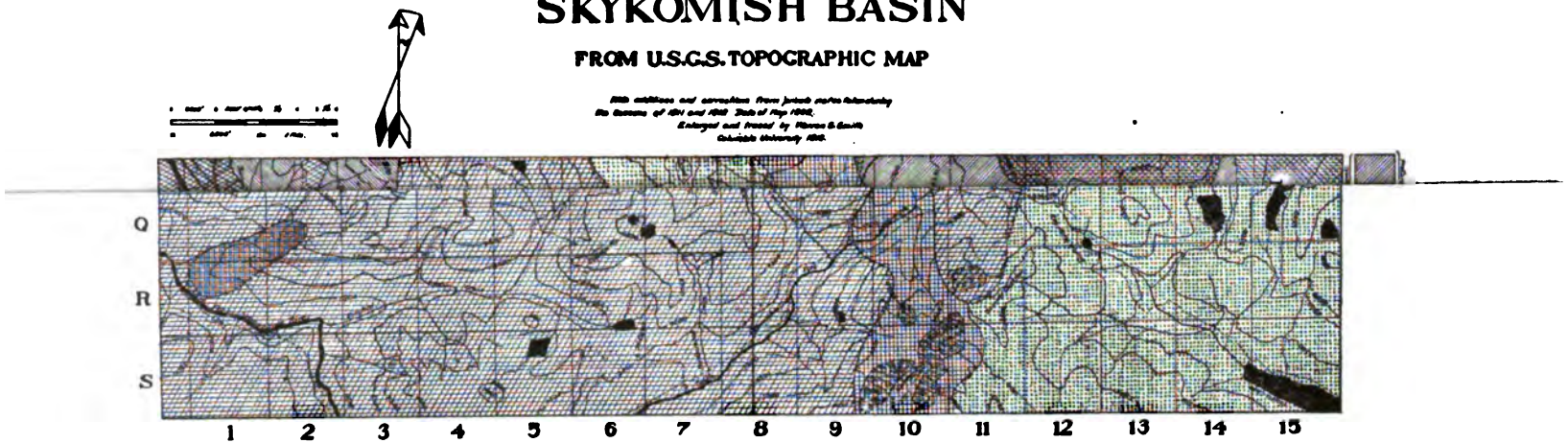
Part I. Petrology.

Geological History.—The earliest or basal terrane present in the Skykomish Basin is a series of pre-Carboniferous schists, followed by Carboniferous quartzites, limestones, and greenstones. The Mesozoic was devoid of sedimentation but in the Jurassic there was a marked period of intrusion resulting in the Mt. Stuart and similar batholiths. Between these two stages, folding occurred. The Mesozoic closed with a period of marked dynamic effects and the Tertiary opened with continental sedimentation in which Eocene arkoses were deposited. Subsequently, volcanic activity predominated in the Miocene and some 5,000 ft. of andesite tuffs were accumulated. In late Miocene there was a recurrence of batholithic intrusion which yielded the most important terrane here present—the Snoqualmie batholith which covers a known area of 130.9 sq. mi. In late Miocene and in Pliocene a peneplane was developed and later uplifted to form a plateau. The Pleistocene was a period of glacial occupancy resulting in thin mantles of till not widely distributed in the area. A certain thin ash bed at the grass roots is evidence of recent volcanic activity.

Easton Schist.—This formation consists of quartz and mica schists which are usually intensely folded and always stand at high angles, striking northward. They outcrop in a north-south belt occurring in the northwestern quarter of the Basin, which is drained chiefly by Beckler River and Surprise Creek, comprising 22.95 sq. mi. of the total area. (Fig. 1.)

The schists are dark grey to greenish, banded, usually intricately folded, fine-grained rocks, often cut by cross joints, by quartz or other acid dikes, and often rich in mica, which increases the schistosity. Microscopically, the rock shows quartz grains, with feldspar and clayey minerals, to have been the

*This article represents part of a report prepared for the Washington State Geological Survey, but not heretofore published.


SKYKOMISH BASIN
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chief original components. Metamorphism has left an indurated rock of schistose structure and lutitic texture in which biotite, muscovite and pyroxene occur as recrystallization minerals. Many veinlets of quartz, varying in width from 0.025 mm. to 50 cm. cross or join each other indiscriminately; the quartz grains are very small (0.03 mm.) The dark color seems to be due to an original content of carbonaceous matter. A prominent cleavage, depending upon orientation of grains, gives the rock its schistose structure and it may be classified as a schist, varying from a quartz schist to a mica schist, of sedimentary origin. (Fig. 2.) On lithological grounds, it is classified with the Easton schist of Geo. O. Smith, as described from regions to the south and east.

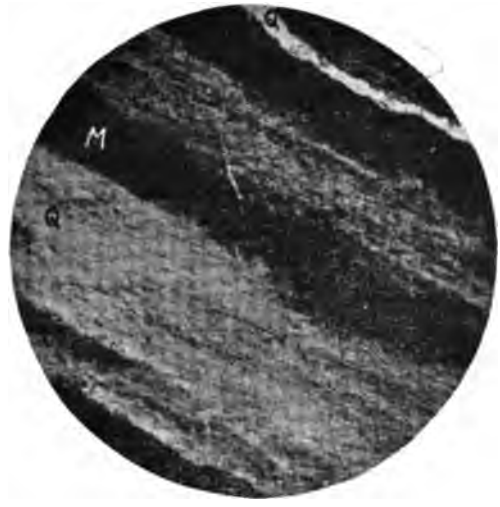


Fig. 2. Easton Schist. Q, quartz. M, metamorphics (biotite, muscovite, iron oxides, carbonaceous matter.)

Peshastin.—Parallel to the Easton schist in the northwestern quarter there is a series of metamorphic rocks composed of quartzites with intercalated limestone lenses and injected igneous rocks of basic composition. These dip at high angles and strike about north-south, being developed in a north-south belt about 4,000 ft. wide across the Skykomish River, west of Grotto, occupying an area of 1480 sq. mi. (Fig. 1.) The limestone is developed chiefly in C 2, D 2, and E 2, with a smaller outcrop in G 2. The most important of these lenses

lies near the middle of the Peshastin series. The limestone is coarsely crystalline with crystals up to 1 in. diameter, and is 150 to 200 ft. thick. Lattice structure on the weathered surface is a result of differential weathering along gliding planes.

The sedimentary series includes quartzite and lenses of limestone. The quartzite is a fine-grained, gray, brecciated silicarenyte. The western limestone lense is a saccharoidal, white to blue mottled, crystalline limestone intimately associated with chert which weathers out to yield a rough, concentrically ridged surface, varying in thickness up to 40 ft. The eastern limestone lense is a coarsely granular, blue, massive, crystalline rock varying in thickness up to 250 ft. It outcrops in several places on Lowe Creek and can be traced across the mountain to the vicinity of Katharine Falls on the Money Creek side. The quartzite is of sandy texture, and is brecciated and reconsolidated with epidote veinlets; chlorite and other secondary minerals are also present. The quartz fragments are small (0.1 to 0.3 mm. diameter), angular, and irregularly distributed.

Associated with the sedimentary series and so intimately mixed with it that separation on a small scale geologic map is usually impracticable, is a group of igneous rocks of basic composition belonging to the augite-andesite, olivine-free gabbro group. They vary from grey to green and black in color, and texturally from felsitic through porphyritic and finely granitoid to medium coarsely granitoid. This rock is usually almost entirely composed of secondary minerals, and would be called a greenstone. Of these secondaries, epidote, chlorite, kaolin, carbonates, sericite, quartz, iron oxides, uralite, and saussurite have been recognized. Where the rock is fresh enough for identification of primary minerals, as at a point on the Apex Railroad three miles from Berlin, the rock consists of augite, a plagioclase with extinction angles of about 25° and otherwise identified as labradorite, biotite, and enstatite. Magnetite, quartz, and orthoclase occur as accessories. The augite is often uralitized and always shows leaching effects. Sometimes the rock is porphyritic and then the phenocrysts are feldspar in a cryptocrystalline groundmass. (Fig. 3.)

There is fossil evidence that the limestone is Palaeozoic. Smith and Weaver have arrived at the same conclusion on independent evidence, the latter having found the genera Fusulina and Orbitulina in the quartzites of Mt. Pilchuck.[1] The fact that both quartzite and igneous members are so thoroughly altered by both static and dynamic processes is evi-

Fig. 3. Gabbro. (L, labradorite. A, augite. U, uralite. M, magnetite. S, sericite. Note the fractures and broken feldspar twins.)

dence that they are pre-Tertiary. They are assigned in this study to the Carboniferous and their identity with the Cache Creek series of British Columbia is suggested. The close association of the igneous members with the Peshastin series is the only clue to their age. They may be more recent but the present evidence would assign them also to the Carboniferous.

From the International Boundary Survey, a degree further north, Daly has described the Carboniferous Chilliwack series, which corresponds rather closely to the Peshastin series[2]. (See also G. O. Smith and F. C. Calkins, Bull. 235, U. S. G. S., 1904, and G. M. Dawson, Bull. Geol. Soc. Am., Vol 12, 1901, p. 70).

Tye Soda Granite.—This batholith, lying in the northeast corner of the quadrangle, consists of a massive, comparatively

[1]C. E. Weaver, Index Mining Dist. Bull 7, Wash. Geol. Surv. 1912, p. 38.

[2]R. A. Daly, Geol. Surv. Can. 49th Parallel Surv. Memoir 38, 1912, p. 514.

coarse-grained, granitoid, greenish-white, igneous rock composed of orthoclase, plagioclase, quartz, hornblende, and biotite, the latter in irregular lustrous brown flakes and the hornblende in recognizable green prisms. The feldspar weathers out to a lime-colored mass, leaving the anhderal quartz grains in relief, often giving the rock the appearance of a mosaic. The rock is typically fresh, but the feldspar is always slightly clouded. One large outcrop of this terrane occupies the northeast corner of the Skykomish Basin on Tye River, Martin Creek, and Deception Creek. It is well shown along the Great Northern railway between Scenic and the new village of Alpine. There are two stocks directly associated with the main batholith, the smaller being separated from the main batholith only by a narrow band of Eocene sandstone. It lies in J 13, Fig. 1. The large stock is on Beckler River and is therefore called the Beckler stock. Texturally this rock differs from that of the parent batholith in that it is more coarsely granitoid so that the quartz, biotite, and feldspars are readily determinable in a hand specimen. A band of Easton schist separates this stock from the principal batholith. A narrow roof pendant of Easton schist extends from A 14 southward but the granite obviously is subjacently continuous. Granite can here be seen including schist fragments.

Microscopically the rock is coarsely granitoid and massive. Two structural features are significant: (1) Rehealed fractures, often running continuously across two or more adjacent grains. (2) Distortion of grains. (a) Flowage of biotite; (b) Breaking of feldspar twins. Both of these are evidence of dynamic metamorphism, at a stage which is important in correlating the batholith. The primary minerals include orthoclase, plagioclase, quartz, hornblende, biotite, in descending order of importance; zircon, apatite, titanite, and augite occur as accessories, and sericite is present in minor amounts as a product of feldspar alteration. The plagioclase has very narrow albite twins, small extinction angles, and constitutes 20% of the rock. The prominence of this soda feldspar leads to the classification of the rock as a soda granite, Feldspars alone are euhedral, ferromagnesians being subhedral, and quartz interstitial. (Fig. 4.)

This soda granite is very near in composition to the granodiorite of the Sierra Nevada. It shows dynamic effects not shown by the Tertiary igneous rocks, and chiefly because of this structural irregularity it is classified as of probably pre-Tertiary age, the dynamic effects being due to the pre-

Fig. 4. Soda Granite. (A, albite. B, biotite. Q, quartz. O, orthoclase.) Note the fractures and distorted biotite as evidence of dynamic metamorphism.

Tertiary upheaval. The soda granite has been seen to include Easton schist fragments and is therefore post-Easton. In looking for Mesozoic periods of batholithic intrusion, the Jurassic is found to have been the greatest of all. It was then that the Cascade-Sierra Nevada granodiorite was intruded all along the central Cascade axis. I. C. Russell,[3] and Smith and Calkins have described it from the Mt. Stuart and neighboring regions in the adjacent quadrangles. Weaver[4] has described it from the Index region adjacent on the northwest, and R. A. Daly[5] has written part of his comprehensive

[3]I. C. Russell, Cascade Mountains in Northern Wash. 20th Ann. U. S. G. S. pt. II, 1898, p. 105.

[4]C. E. Weaver, Index Mining District, Bull. 7. Wash. Geol. Surv. 1912. p. 38.

[5]R. A. Daly, North American Cordillera, Memoir 38, G. S. C. 1912. p. 439-43.

memoir on a cross-section through the Jurassic batholiths.[6] Summarizing the terrane in the contributions referred to, the Osoyoos and Remmel batholiths are specially comparable.

Index Granodiorite.—In the northwest corner of the quadrangle, near Baring, there is an igneous rock belonging to the batholith described by Weaver in the Index region. The quarry at Baring is in this terrane. The rock is rather coarsely granitoid, grey in color, holocrystalline and locally is strongly gneissoid. The surface area is small in this quadrangle—only some four square miles. This exposure is separated by an area of Peshastin schist and quartzite from the main batholith which Weaver has described as occupying 60 square miles in the region to the northwest.[7]

The rock is of granitoid texture and of a massive structure, dynamically affected, so that it shows:

1. Complex fractures cutting continuously across adjacent grains and usually rehealed with epidote, chlorite or introduced quartz.
2. Distortion of grains, including: (a) Bending and flowing of ferromagnesians. (b) Breaking and bending of feldspar twins. (c) Micro-faulting in plagioclase twins.
3. Strain effects shown by variable extinctions. Locally the rock is a granodiorite gneiss and, in addition to the above structural features, shows:
4. Banding of feldspars and ferromagnesians, accompanied by orientation of grains parallel to a single plane.
5. Granulation.

The original minerals of the rock, in descending order of importance, are orthoclase, quartz, hornblende, biotite; with titantite, apatite, magnetite, and augite as accessories; and with sericite, epidote, and chlorite as common alteration products. The plagioclase shows several varieties of twinning, including albite, Carlsbad and pericline. Extinction angles on albite twins of equal symmetrical illumination vary above or below an average of 20°, and the feldspar is andesine. Orthoclase is usually untwinned. Hornblende is green and strongly

[6] R. A. Daly, The Okonogan Batholith of the Cascade Mountain System, Bull. Geol. Soc. Am. Vol. 17, 1906, p. 329-76.

[7] C. E. Weaver, Index Mining District, Bull. 7, Wash. Geol. Surv., 1912. p. 39.

pleochroic. Such composition identifies the rock as a granodiorite, which shows a marked consanguinity with the later batholith lying to the east of the one here described. (Snoqualmie).

The batholith is a part of that described by Weaver in the Index district, which is assigned by him to the Jurassic period of intrusion. It is therefore probably related in time to the Tye soda-granite, being certainly older than the Tertiary Snoqualmie batholith, as evidenced by an additional stage of history.

Swauk Sandstone (Eocene).—This terrane is an arkose with a conglomerate at its base in which there are schist and granodiorite boulders up to a foot in diameter. It grades upward into a grey sandstone, often cross-bedded, which resembles a fine-grained granite when indurated. This sandstone is succeeded by shales and bituminous shales which, in places, include bony coal up to 14 in. in thickness; at some places it is fossiliferous. The shale-sandstone alternation terminates upward in a sandstone member. The Swauk arkose rests uncomformably on schistose granite and is characteristically covered by an andesite. There are three localities or basins where the sandstone outcrops. From north to south these are (Fig. 1): A 7, on Eagle Creek; G 8, on Foss River; and R 14, on Waptus Creek.

The Swauk is characteristically a grey, medium-grained arkose, the fragments of which are angular to sub-rounded, and consist of feldspar, quartz, and ferromagnesians, besides schist fragments. Locally, and particularly at base and top of the series, conglomerate members occur, the one at the base being angular enough to be classed as a breccia. The pebbles are angular, range in size up to several cm. diameter, and consist of schist and acid igneous rock boulders. These schist fragments become less noticeable higher in the column. In the middle of the series there are shaly and bituminous members. These are thin, laminated, ribbon or conchoidal shales, infrequently fossiliferous. Induration effects on both basal and capping members are noticeable. (Fig. 5.)

A typical sandstone was chosen for microscopic study. It came from the shores of Lake Caroline and is fine-grained, grey, mottled with brown specks. As primary minerals there

are quartz, plagioclase and orthoclase; as secondary minerals or alteration products, chlorite, kaolin, epidote, sericite and quartz. The grains vary in size up to ½ mm. and are bound together with quartz, clayey material, and chlorite. Marginally, the Swauk arkose shows induration effects and both bio-

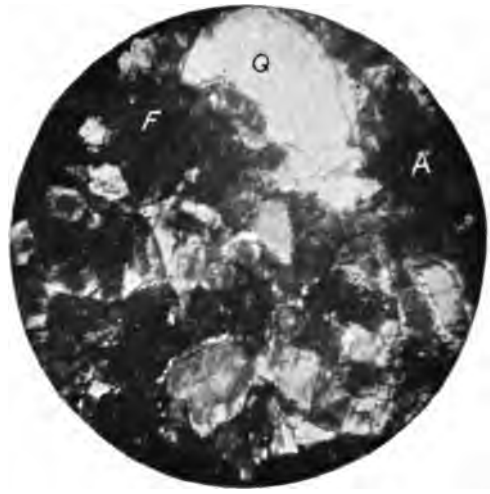


Fig. 5. Swauk Arkose. (Q, quartz. F, feldspar. A, argillaceous cement.) Note angularity of fragment.

tite and muscovite occur as recrystallization minerals, the former in brightly pleochroic plates.

Fossil evidence from the Anthracite Creek region proves the Eocene age of the Swauk arkose. This identifies it with the Swauk of the Snoqualmie quadrangle, which was also identified by F .H. Knowlton as Eocene[8]. It has also been connected areally with this sandstone. The Swauk was described by Smith[9] in the Mt. Stuart region. It is described by Russell[10] and by Spurr[11] from the Monte Cristo district. Thus it is seen to be widely distributed in the Northern Cascades and is probably the most important sedimentary series present.

Keechelus Andesitic Series (Miocene).—This is a series of

[8]G. O. Smith and F. C. Calkins. U. S. G. S. Folio 139, 1906. p. 4.
[9]G. O. Smith, Folio 106, U. S. G. S. 1904, 5.
[10]I. C. Russell, 20th Ann. Rept., U. S. G. S., Pt. II. 1898-99, p. 118.
[11]J. E. Spurr, Monte Cristo Mining District. 22nd Ann. Rept. U. S. G. S., Pt. II, 1900-01, p. 789.

tuffs with intercalated andesite flows, felsitic sheets, and porphyritic dikes. The rock is generally green and fine-grained; it breaks in irregular fragments and is so resistant to erosion as to stand in bold cliffs. Generally it is composed of a dense mass of alteration products, but there are many areas of finely porphyritic, hypabyssal and plenocrystalline as well as

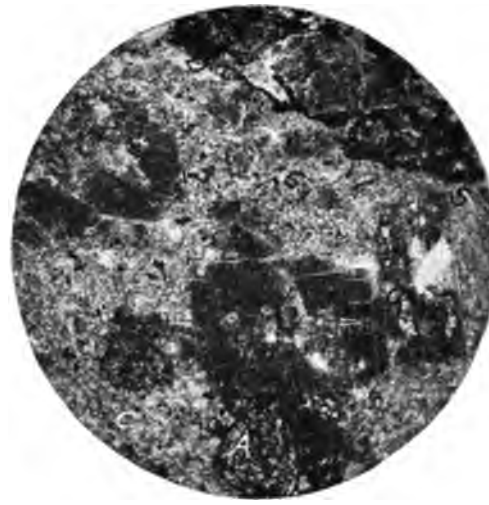


Fig. 6. Keechelus Tuff. (A, augite. F, feldspar. C, chlorite. O, orthoclase. G, groundmass.)

volcanic types of andesite. Three localities occur, only one of which is of important size. This is the long lobster claw-shaped outcrop beginning in A 9 and following the Beckler River to Skykomish. The other claw lies just west of Grotto (B 3) and the arm forms the elevated area called the Mona Ridge. A second area exists in the Chimney Rock area (S 10) and a third on Taylor Creek (O 1). The second is a northward continuation of the Keechelus (Miocene) andesitic series of the Snoqualmie Quadrangle. (Fig. 6.)

The Keechelus terrane is composed chiefly of an indurated tuff in which are fragments of basaltic rock showing flow structure, mixed with quartzitic fragments. The tuffs are amygdaloidal with cavity fillings of zeolites, quartz, carbonates or kaolin outlined with iron oxides or chlorite. The greenish, altered mass is cut by veinlets of introduced quartz,

and introduced tourmaline is frequent. Leaching effects are pronounced. Diallage is replaced with secondary minerals and usually original minerals are only recognized by their outlines. Induration and recrystallization effects show that the rock has been in the zone of anamorphism. Oxidation, carbonation, etc., are evidence of metamorphism in the katamorphic zone. Incipient recrystallization of biotite is noticeable, especially in the neighborhood of the Snoqualmie batholith and it was probably the latter intrusion that gave rise to anamorphic metamorphism and to the introduction of tourmaline. The tuff breccias were probably genetically connected with the vulcanism that is known to have occurred in late Tertiary times in the Northern Cascades. The several zones of which Mt. Rainier is the type, are hypersthene andesite in composition, and we may well believe that the Keechelus tuffs were explosion emissions of Miocene valcanoes of a similar nature. Such a history would account for their irregular distribution, and also for the presence of phenocrystalline andesites and dacites which were possibly fissure eruptions of these same volcanoes. Being volcanic in origin, then, we find beds which Weaver says are 5,000 ft. thick being leached and kaolinized in the vadose zone until, except in the hypabyssal types, all original minerals are destroyed. Then came the intrusion of the Snoqualmie batholith which gave rise to recrystallization effects, induration and mineralization. More recent erosion has uncovered these indurated tuffs without destroying the induced structure.

The primary minerals and their traces prove the original composition to have been that of a pyroxene andesite with augite and diopside, and plagioclase which was labradorite in composition, with lesser amounts of biotite, and with apatite, titanite, zircon and magnetite as accessories. At present the rock is composed almost entirely of alteration products, recrystallized and introduced minerals. In the first group appear carbonates, kaolin, iron oxides, chlorite, epidote, quartz, saussurite, uralite, carbonaceous matter, and leucoxene. In the second group we find biotite and zeolites; as mineralization or introduced substances there are pyrite, tourmaline, and quartz. Metamorphism is far advanced, but the unaffected flow structure of basaltic fragments points to the absence of

dynamic or orogenic metamorphism. Spurr has described[12] these metamorphic effects as "metachemic" but the Van Hise term "static" seems more descriptive. (Fig. 6).

In Q 10 occurs a rock associated with the andesite, which was microscopically determined to be a silicified quartz diorite porphyry. It has the following essential primary minerals: Quartz, oligoclase, orthoclase, pyroxene, and biotite; with magnetite apatite, and titanite as accessories; and with uralite, epidote, quartz, sericite, iron oxides, saussurite and zoisite as secondaries, and with introduced quartz. This rock shows the usual static metamorphic effects.

As stated previously, the andesite is directly connected with the Keechelus series of the Snoqualmie quadrangle, which is described by Smith and Calkins.[13] A series which is entirely comparable has been identified in the Monte Cristo region by Spurr.[14] Weaver's West Index series[15] is comparable from his description, though he considers it to be late Eocene or Oligocene in age. The Keechelus series noticeably bakes the Swauk arkose sandstone where dikes cut the latter, and at contacts. Hence the series is post-Swauk. Since the above metamorphism is attributed to the Snoqualmie batholithic intrusion, the Keechelus must be pre-Snoqualmie. It is only fair to say that as far as the Skymonish Basin is concerned, the Keechelus series might have begun its formation in Oligocene. But the Snoqualmie quadrangle yields proof of the Miocene age of the series.

Snoqualmie Granodiorite.—Geologists have observed that great orogenic periods are frequently preceded by an igneous intrusion of great importance. It has been seen that the late Mesozoic upheaval was preceded by intrusion of the Jurassic batholith. Hence it is not surprising that the late Tertiary (Pliocene) upheaval was preceded by a batholithic intrusion. That this plutonic rock is of almost identical composition with its predecessor suggests that the two may be derived from an undifferentiated magma which had merely remained quiescent until erosion had again disturbed isostatic equilibrium

[12]22nd Ann. Rept. U. S. G. S., Pt. II, 1900-01, p. 795.
[13]Smith and Calkins, U. S. G. S. Folio 139, 1906, p. 8.
[14]J. E. Spurr, Ore Deposits of Monte Cristo, 22nd Ann. Rept. U. S. G. S., Pt. II, 1900, p. 795.
[15]C. E. Weaver, Index Mining District, Bull. 7, Wash. G. S., 1912, p. 44.

after the lapse of an entire era of geologic time. The Snoqualmie granodiorite batholith was first described in the quadrangle of that name. It is directly traceable northward into the Skykomish area where it predominates areally.

The Snoqualmie granodiorite differs essentially in two respects from the Tye soda granite, which is supposed to be the local representative of the Mt. Stuart batholith. First, the latter is characteristically coarser grained, usually with larger grains of feldspar and ferromagnesians, whereas the former is less coarsely crystalline and both quartz and feldspars are hard to distinguish with the naked eye. Second, microscopically, the latter has a soda plagioclase while the former has a soda-lime plagioclase; the latter also shows the result of dynamic processes not in evidence in the former. The Snoqualmie granodiorite is a medium granitoid, greenish-grey, relatively fresh igneous rock consisting of plagioclase, orthoclase, quartz, hornblende, and biotite, named in descending order of importance. It is seldom weathered, but shows some differentiation effects in the form of relatively basic nodules. The rock is massive, not severely jointed, is very resistant to erosion, and is never faulted.

The southwestern half of the quadrangle, containing the drainage areas of Miller River and Taylor Creek, Foss River and most of the Snoqualmie River, lies on the granodiorite terrane (Fig. 1.) Lying in a rough triangle with its apex near Berlin, it rapidly broadens southward to nearly the complete width of the quadrangle; the known part of the batholith lying to the south in the Snoqualmie quadrangle is similarly shaped except that its geometric relations are reversed so that the known outcrop makes a huge diamond with a major axis 30 miles long, parallel to the Cascade axial trend. Geologically it is bounded on the northeast and north, and apparently on the west, by Keechelus tufaceous andesites, on the northwest by Palaeozoic metamorphics, and on the east by Swauk arkoses. A much smaller outcrop, which is undoubtedly subjacently connected with the above, lies north of Berlin and is roughly a right-angled triangle with a base on Eagle Creek and its adjacent angle toward the north. It is similar in every way to its larger relative.

As seen above, the batholith is identical with the Snoqualmie

occurrence, but it has no positive correlation with any other. Smith has considered it late Miocene in age.[16] It contains metamorphosed Miocene tuffs and hence is Miocene or later. To allow for momentous events of the Pliocene it seems necessary to date the intrusion as early as possible. Therefore Smith's relation seems justifiable. R. A. Daly has correlated his Tertiary batholiths with this occurrence. The Cathedral granite, and the Castle Mountains, Similkameen and Chilliwack granodiorites are so correlated[17] and the description of the three latter might almost serve for the Snoqualmie batholith, even falling in the same quanitative pigeonhole—"tonalose."

Under the microscope it is seen that the feldspar content is large. The ferromagnesians are hornblende of a common green variety and lustrous brown biotite. The feldspar is approximately two-thirds plagioclase and the remainder orthoclase. The former is characteristically anhedral, the latter, except on the margin of the batholith, anhedral untwinned. Quartz is interstitial, variable in amount and contains solid, liquid, and gaseous inclusions. The accessories are: apatite, titanite, magnetite, an occasional zircon, augite and pyrite. The texture is medium granitoid with tendencies toward a porphyritic habit of the soda-lime feldspars; the structure is massive and secondary or induced structure is attributable to dynamic processes. The rock is fresh but always shows a slight clouding of the feldspars with sericite. On the margins of the batholith, and where leaching has been effective, alteration is more complex and often the ferromagnesians are completely destroyed, yielding epidote, chlorite, iron oxides and sericites.

The plagioclase shows a cleavage of 17° to 20° from albite twins which have equal symmetrical illumination. The index of refraction is almost that of quartz. These properties show is to be andesine. Porphyritic plagioclases are zonally grown with a center of andesine and a margin of oligoclase. Only rarely, as on the eastern side of the batholith (N 12) does the orthoclase occur anhedrally. Here it shows Carlsbad

[16]G. O. Smith and F. C. Calkins. Folio 139, U. S. G. S., 1906, p. 2.

[17]R. A. Daly. Geol. Surv. of Can. Mem. 38, 1912, pp. 455-59, 469, 493, 534-40.

twinning and the rock corresponds closely to a granite in composition. Nearly the same thing is true on the western margin (Q 1) where quartz and orthoclase show graphic intergrowth. In fact, the granitic phase seems to be a marginal characteristic, probably due to a slight magmatic differentiation. Hornblende shows medium extinction angles and is

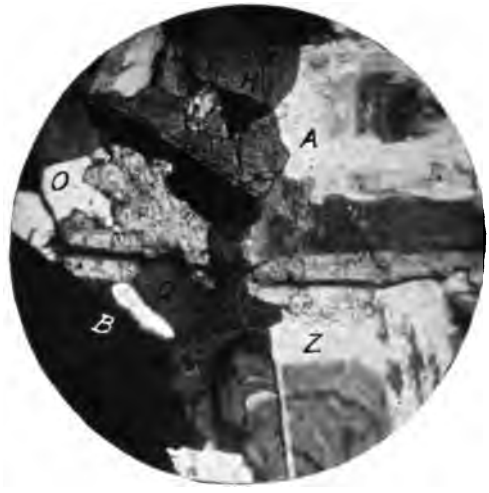


Fig. 7. Granodiorite. (H, hornblende. B, biotite. Z, zonally grown plagioclase. A, andesine. Q, quartz. O, orthoclase.) Note absence of dynamic effects.

sometimes beautifully twinned; biotite is brown to yellow and strongly pleochroic, and often these ferromagnesians are poikilitically intergrown. In the order of crystallization, plagioclase is euhedral and oldest, and ferromagnesians subhedral and paragentically intermediate. Quartz and orthoclase are typically anhedral and therefore youngest. (Fig. 7).

Dark colored nodules occur in the rock, of a slightly more basic composition. A more important variation is the presence of dikes of an aschistic nature cutting through joints in the batholith, probably by injection as a last stage of dying vulcanism. They consist of orthoclase, quartz, albite, muscovite, hornblende, and biotite, with zircon, magnetite, and apatite as accessories. These aplite dikes are very white, are massive granitoid, and vary in thickness from 1 mm. up to 100 meters (as at the head of Lake Dorothy). Infrequently, as at Mt.

Cleveland, and on the Middle Fork of the Snoqualmie (Q, R, 1, 2), small areas of this rock are apparently intruded as small stocks into the granodiorite. The batholith has forced apophysal dikes of a graphic granite ashistic in nature into the Keechelus andesites (C 7 and D 5). Megascopically these are badly leached, white, granitoid rocks.. Microscopically they are composed of plagioclase, graphically grown quartz, and orthoclase; also (D 5) spodumene. Magnetite and titanite are the common accessories. The plagioclase is euhedral andesine showing albite and pericline twinning. These appear to be pegmatite dikes and were undoubtedly given off by the batholith.

The effects of the batholith intrusion on the Swauk sandstone were described above. The effect on Easton argillites is almost as marked. A hornfels from L 11, near Lake Caroline, shows incipient recrystallization of biotite (yellow to brownish yellow pleochroism). The quartz is finely divided (1/50 mm.) and remarkably well-rounded; 30% of the whole is argillaceous cement and it is this that has offered material for recrystallization. Where the granodiorite approaches the Palaeozoic series, especially the limestone, there have been marked contact effects. There is such a place on Lowe Creek, where contact metamorphism has resulted in extremely coarse calcite containing red garnets showing beautiful crystals (rhombic dodecahedrons and tetragonal trisoctahedrons twinned with the dodecahedron), green garnet, and magnetite. The effects of the intrusian may be summarized as: (1) Induration. (2) Mineralization and introduction of tourmaline, pyrite, quartz, etc. (3) Contact effects, including recrystallization.

Part 2. Economic Geology.

History of the District.—Prospecting of the Berlin mining district dates to the extension of the Great Northern railroad across the Cascades in 1892. The Apex and the Cleopatra were among the first properties to be located (1892). Little was done toward development until about 1897 when the county built 7½ miles of puncheon road on the west side of Miller River to tap several of the most promising prospects. On the Money Creek side, the Apex packed out on horseback

about $80,000 worth of ore before the cutting of 6½ miles of wagon road in 1901.

Soon after this came the climax of early activity in the district. A small concentrating mill was installed at Berlin, but it soon proved a failure and was abandoned. The Cleopatra, Coney, Aces Up and Mona, on Miller River, and the Apex, Kimball Creek and Gold Mountain properties, on Money Creek, reached a maximum of their activities between 1900 and 1905. Thousands of feet of tunnel were driven and a great deal of money was spent, most of it injudiciously. The Berlin fire, early in 1906, was a heavy blow to the industry, and later years have shown a lessened activity, varied only by the completion, in 1909, of a narrow gauge railroad to the Apex mine. At present the mines are at a low ebb of development, but there is nevertheless a well founded hopefulness that the future may witness activity in the district.

Nature of Ore.—The ore minerals are chiefly original sulphides. Of these, the following have been seen: Arsenopyrite occurs in the workings of the Cleopatra and neighboring mines. It is anhedral and is associated with quartz as one of the earliest mineralizers. Pyrite occurs very generally in all the mines, and in those associated with the andesite felsites it is the chief mineral. It occurs in two generations and is both euhedral and massive. When euhedral it is generally cubical, but in the Lillian tunnel at Kimball Creek it is pyritohedral. It is one of the earliest minerals and usually persists to association with the youngest. With it is gold but probably no other values. Sphalerite is found in many localities but is particularly abundant at the Seattle Cascade, where it takes the place, in depth, of galena. It is usually associated with galena and often the two are intimately mingled. When occurring with chalcopyrite, as in the Mona, it is distinctly older. Galena is commonly associated with sphalerite, as noted above. It is usually euhedral and is one of the younger minerals. It always occurs nearer the surface than the sphalerite, by which it is gradually replaced in depth. It is usually argentiferous. Chalcopyrite is a common sulphide, and is probably the original source of all the copper ores of the region. It seems to be associated with the surface ores and is seldom found in the deeper zones, where these have been penetrated.

It is best shown at the Mona, though commonly occurring throughout the Miller River division. It has not been noted in any quantity on Money Creek. Stibnite occurs in prismatic needles and also as fine disseminations in the ores of the Cleopatra and neighboring mines. It is also found in the surface workings of the upper tunnel of the Grand Central. It is probably a late sulphide, though its relations are not evident. Bornite, derived from chalcopyrite, occurs as a surface mineral wherever chalcopyrite is present in important amounts, especially at the Mona.

Oxidized ore minerals are: Malachite, as an oxidation product in the surface workings of all copper bearing mines. Common in the district as stains but never an important mineral. Hematite, an infrequent alteration product. Limonite, a common surface alteration product.

Rarer minerals are: Molybdenite, in prospects in the upper Miller River Basin, especially in the Serpent tunnel. Barite, Coney mine, Lollingite, tetrahedrite, and dyscrasite, described from Cleopatra mine.

Gangue minerals comprise the following: Sericite is the ultimate decomposition product of the granodiorite, and has been identified in the vein, or near it, at every mine. Often it constitutes almost the whole gouge, but is more commonly mingled with quartz. Quartz is always present in the gangue, sometimes making almost the whole of it. It occurs in several generations, is often zonally grown, is both euhedral and massive, and occurs as an induration mineral replacing sericite. It is often seen in veinlets, in nodules, or in complete replacements as granular, typical vein quartz. It is one of the earliest vein fillings and, less frequently, also the latest. Where both quartz and calcite occur, the latter is always later. Calcite occurs as the latest vein filling and is apparently still being formed, as will be noted later. It is both euhedral and massive, and often replaces feldspars as a granular mass. It seldom occurs as an early mineralizer and was probably one of the last minerals to be introduced. Chlorite replaces ferromagnesians particularly in the tuff series; it often fills minute veinlets. Epidote is less common than chlorite but occurs similarly. Tourmaline, in black columnar, prismatic needles, forms a great segregation at the Una mine, and is

evidence of pneumatolytic action. Apatite, in small prisms, and as anhedral fragments, is common in vein filling, being especially abundant at the Mona. Magnetite is very generally present as an accessory. Garnet is noted only as a contact mineral.

Difficulty of treatment.—Several efforts have been made to concentrate the ores, but thus far they have been unsuccess-

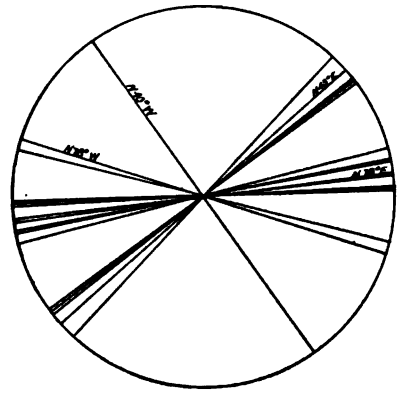


Fig. 8. Strikes of Veins, Berlin Mining District.

ful. The finely divided condition of the sulphides probably will make necessary some other treatment than the usual water concentration. The sulphides form a smelting ore and the only successful treatment so far has been smelting. In later years shipment has been made to Tacoma. The blende that occurs in some of the deposits is detrimental, while the galena is, of course, desirable. No free milling ore is known, but both gold and silver occur in association with sulphides.

Type of ore deposit.—Several sets of joints are prominently associated with mineralization in the Berlin distict, a northeast set, an east-northeast set and a lesser west-northwest set. These are shown graphically in Fig. 8, where it will be seen that the average strike is N.78°E. for the most important set, N.45°E. for the northeast set, and N.78°W. for the west-northwest set. The latter set occurs outside the granodiorite area. In the Monte Cristo area, 40 miles north, Spurr finds three sets of prominent jointing, the average strike of the most important being N.70°E., the second N.45°E., and a lesser

N.45°W.[18] In the Index area, 14 miles northwest, Weaver finds two sets, one striking N.45°E., and the other N.75°W.[19] Thus these prominent strikes are fairly constant over considerable areas.

In general the joints are tightly closed and become apparent only after prolonged weathering, or in quarrying. Where seen in the field, they dip steeply, nearly always at angles in excess of 70°. This is also the condition in neighboring areas. It is true everywhere in the mineralized veins of the Berlin district.

Certain of these joints have been circulating solutions, a choice probably governed by the vertical extent and relative strength of the joints. These solutions have leached the granodiorite on both sides of the joints, in such a way as to form fissures.[20] The first minerals to be removed were the ferromagnesians, which, near the mineralized part of the vein, are usually entirely destroyed. Later the feldspars were altered to a mass of secondary products. Sericite is the chief product of this static metamorphism and takes place somewhat on the following formula:

$$3KAlSi_3O_8 + H_2O + CO_2 = KH_2Al_3(SiO_4)_3 + K_2CO_3 + 6SiO_2$$[21]

a process accompanied by 13% loss of volume, even if none of the secondary products were removed. This loss of volume is important in the explanation of crustification. The plagioclase alteration is less simple, but the final products are sericite, quartz, and carbonates. In these reactions it will be noted that soda is eliminated while potassium is concentrated. Magnesia is also eliminated while calcium changes to a carbonated form. No quartz is lost and there is an increase of carbon dioxide. Thus the leaching processes are seen entirely to destroy the original character of the rock. It will later be seen how this change effects mineralization, and proof will be set forth that it was effected by rising solutions. The distance to which such leaching spreads is variable. In the

[18] J. E. Spurr. Ore deposits of Monte Cristo, Wash. U. S. G .S., 22d An. Rept., Pt. 2, 1901, p. 807.

[19] C. E. Weaver. Index Mining District. Bull. 7, Wash. Geol. Surv., 1912, p. 65.

[20] W. Lindgren. Genesis of Ore Deposits. 1901, p. 610.

[21] W. Lindgren. Metasomatic processes in fissure veins. Trans. Am. Inst. Min. Eng., Vol. 30, 1900, p. 608.

granodiorites, it varies from a few inches between walls, up to a maximum of about 40 ft., and this variation is not consistent for any known vein. In the tuffs, the distance to which the leaching spreads is considerable but indefinite.

Thus we have seen how circulating solutions have enlarged joints into fissures along which circulation is comparatively free. It is the common admission of both the schools of geologists that the phenomena of sericitization and the intermediate stage of dechloritization take place as the result of water circulation. The following paragraph is presented as evidence that the solutions were circulating upward rather than descending. Other writers agree to the rising or ascending solution hypothesis in the neighboring districts of Monte Cristo and Index.

The evidence of pneumatolitic action is not, on the other hand, recorded, and this, besides the presence of arsenopyrite, is evidence that the mineralization was by ascending solutions. There are three lines of evidence. (1) The presence of apatite in the Mona. It occurs here both in the anhedral form and as prismatic needles and constitutes an extraordinarily high proportion of the gangue. This occurrence alone might be otherwise explained, were it not for the corroborating evidence (2) of tourmaline at the Una. This tourmaline occurs as a mass of black, prismatic needles of considerable areal extent. Tourmaline is the one reliable signature left by the process of pneumatolysis, and has never been described as of any other origin. Stelzner has noted the association of arsenopyrite, pyrite, blende, galena, and other sulphides with tourmaline and apatite, at Freiberg.[22] This is one of the earliest records, but from then until 1914, tourmaline has been recognized as a criterion of pneumatolysis.[23] H. V. and A. N. Winchell have described black tourmaline of a very similar sort in a quartz monzonite in association with sulphides at the Blue Bird mine in Montana.[24] (3) The occurrence of molyb-

[22] A. Stelzner. Studien über Freiberger Gneisse und ihre Verwitterung producte. Neues Jahrbuch. Vol. 59. Band I, 1884, p. 272, et seq.

[23] W. Lindgren. Mineral Deposits. 1914, p. 611 et seq.

[24] H. V. and A. N. Winchell. Notes on the Blue Bird Mine. Ec. Geol., Vol. 7, 1912, p. 287-94.

denite, which appears as a mineral in the prospects about the head of Miller River Basin, particularly at the Serpent, in L 2.

Classification.—Under Kemp's classification of ore deposits, the Berlin type would be grouped with those "deposited from solution" and would fall in the subgroup of "true fissure veins".[25] In Weed's classification, it would be grouped with the gas-aqueous deposits.[26] In Lindgren's classification it would be grouped as a high-temperature deposit under "introduction by ascending solutions carrying emanations from an igneous magna",[27] and various veins in the district might be further classified under the system suggested by this author for fissure deposits.[28] For the purpose of this paper it will be classed as a fissure vein deposited by pneumatic-hydato-lytic (gas-aqueous) ascending solutions. Lindgren has defined a fissure vein as "a mineral mass tabular in form, as a whole, though frequently irregular in detail, occupying or accompanying a fracture or set of fractures in the enclosing rock; this mineral mass has been formed later than the country rock and the fracture through the filling of open spaces along the latter, or through chemical alteration of the adjoining rock".[29]

Mineralization.—We have seen how the country rock was sericitized after leaching. Subsequent to this there was a period of mineralization. This is evidenced on the margins of the Snoqualmie batholith by induration with introduced quartz, which often makes up as much as half of the volume of the rock. This is typical vein quartz. As a similar process, near ore veins, we find induration with quartz, sometimes along definite joints. Carbonates perform a similar role in the vicinity of the ore veins. This is particularly true in the Keechelus tuffs where, as at the Mona, carbonate has replaced much of the original country rock. Often feldspar crystal outlines are seen to be replaced by carbonate. In the Grand Central, carbonate veinlets cut quartz veinlets and are

[25] J. F. Kemp. Ore Deposits of the United States and Canada. 1906, p. 58.

[26] W. H. Weed. Ore Deposits near Igneous Contacts. Ore Deposits, 1913, p. 366.

[27] W. Lindgren. Mineral Deposits. 1914, p. 188.

[28] W. Lindgren. Genesis of Ore Deposits. 1901, p. 515-612.

[29] W. Lindgren. Metasomatic Processes in Fissure-veins. Trans. Am. Inst. Min. Eng., 30, 1900, p. 580.

distinctly later. Here also, crystalline carbonate occurs with vein quartz between it and the country rock. It is thus distinctly younger.

In the Coney tunnel, 1600 ft. from the surface, carbonated waters trickle from the fissure near the footwall and run across steel rails, depositing on them a calcareous tufa. A

Fig. 9. Calcite. Showing growth along crystallographic axes. This deposit is only six or seven years old.

thin section of this deposit shows it to be crystalline; index of refraction, 1.6; birefringence high; uniaxial, and colorless. The grains are markedly angular, varying in size up to 1 m (See Fig. 9) They show growth along the crsytalligraphic axis. It is believed that these waters are juvenile and that the formation of this tufa represents the method of vein filling in its very last stages. In the formation of the gangue, then, quartz is the older and calcite always the latest gangue mineral to be formed.

Beginning with the earliest introduction of quartz, while the solutions were still very hot, sulphides were syngenetically introduced. At first arsenopyrite was alone, but gradually massive pyrite came to be deposited with the arsenopyrite. As the temperature decreased sphalerite and chalcopyrite were formed, and lastly galena and stibnite. There is no demarca-

tion between these epochs of sulphide deposition. Their formative periods overlap and often several were contemporaneously formed, but there is evidence that sphalerite began its deposition before galena, and that pyrite was formed before sphalerite. This evidence is that of banding or crustification, as the term was used by Posepny. This banding of the

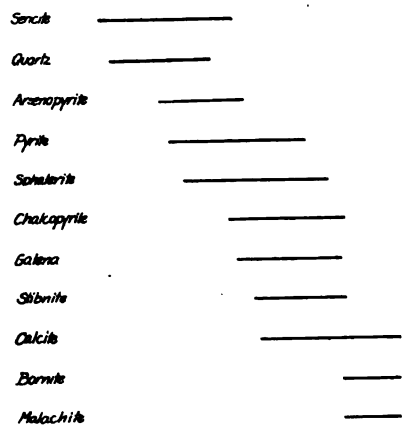


Fig. 10. Paragenesis of Ore Minerals, Berlin Mining District.

ores is not a general law, but can usually be made out in the ores occurring between granodiorite walls. The evidence of this paragenesis is tabulated in Fig. 10. Thus, the process of mineralization, begun with the introduction of quartz, was continued by the deposition of a series of sulphides, and is still continuing as the introduction of carbonates.

Ore Deposition.—Perhaps no one factor is more suggestive of the origin of ore deposits than the occurrence of mineral springs. A deep-seated carbonated spring has just been mentioned. Two other types are worthy of notice: (1) hot springs carrying sulphur; (2) cold springs. No hot spring exists on the quadrangle, but there art two such springs immediately adjacent. The first of these is about one mile east of F 15. It contains hydrogen sulphide and issues from the ground at 112° F., in sufficient quantity to fill a 2-in. pipe. Its waters are used in a sanitorium at Scenic. The second hot spring is situated on the Middle Fork of the Snoqualmie about one mile south of S 4. It spurts with considerable force and

volume from a joint in granodiorite which is lined with vein quartz, at a temperature of 130° F. An analysis of the waters of the Scenic hot spring shows, in grains per gallon:[30]

Total solids	9.9.	Silica	1.34
Chlorine	0.87	Sodium	1.63
Iron	0.76	Potassium	0.34
Calcium	2.33	Sulphur dioxide	0.52
Magnesia	1.1	Ammonia	0.00058

The cold springs are located in the Berlin Mining District. The lesser is on the West Fork of Miller River, about 5¾ miles from Berlin, and the latter, called "Soda Springs", is on Money Creek (E 3) about 2¼ miles from Berlin. It is a chalybeate spring and shows considerable deposits of iron. An analysis of water yields, in parts per mille:[30]

Total solids	0.5473	MgCl	0.1693
SiO_2	0.0078	$MgSO_4$	0.0935
Al_2O_3 & Fe_2O_3	0.0150	Na_2SO_4	0.9331
$CaSO_4$	0.0529	KCl	0.9267
$CaCO_3$	0.5627	CO_2	1.4720

This latter spring is located near the fissure vein which is intersected by the Grand Central and Kimball Creek tunnels, and it is possible that these mineralized waters are connected genetically with the ore deposits, as is suggested very forcibly by the high quartz and carbonate content. It will be recalled that the phenomena of silication and of carbonation are especially prominent in the vein formation.

All the foregoing argument tends toward the conclusion, already arrived at by Spurr[31] and by Weaver,[32] that the ore deposits were derived by deposition from uprising solutions. The conception added by the present study is that of the associated pneumatolytic action that accompanied or preceded the hydatolytic action. It is conceived that, while the subjacent granodioritic magma was still hot, gases penetrated along certain joints bearing halide and other gases which resulted in the formation of apatite, molybdenite, and tourmaline. With progressive cooling and approaching close of

[30]H. O. Byers. An. Rept. Wash. Geol. Surv. Vol. I, 1901, p. 292-3.

[31]J. E. Spurr. Ore Deposits of Monte Cristo. Mines and Minerals. Vol. 23, p. 204-206.

[32]C. E. Weaver. Index Mining District. Bull. 7, Wash. Geol. Surv., 1912, p. 65.

volcanic action, mineralized solutions circulated freely along the joints and, while still very hot, above 600° C. probably, deposited arsenopyrite and pyrite. Subsequently the sulphides of copper and zinc were deposited and then those of lead and antimony. The final stage is still proceeding and is that of the deposition of carbonate as the last stage of dying volcanism.

These mineralized solutions circulated along fissures. Where the walls of these fissures were massive granodiorite, the solutions were confined to narrow zones and at times no precipitation at all took place, resulting in lenticular shaped ore deposits, of the true fissure vein type. Where the walls were more porous, as in the Keechelus tuff series, the mineralized solutions spread, and no definite walls can be found, mineralization merely dying away laterally from a plane of maximum circulation. The Mona vein is of this latter, Butte or replacement, type of fissure vein.

Veins occurring in the granodiorite terrane often show a more or less definite banding or crustification. Poorly defined and poorly oriented vugs are often found partially filled with euhedral quartz and other crystals extending into them. This banding admits of a fairly satisfactory determination of the general paragenesis of the minerals. (See Fig. 10). This paragenesis shows the successive stages of mineralization to have been about as follows: 1. Sericite. 2. Quartz, arsenopyrite, pyrite. 3. Chalcopyrite, sphalerite. 4. Galena, stibnite. 5. Calcite.

These stages naturally overlap, but a careful study of a large number of banded ores from various parts of the district shows this to have been approximately the order of deposition from the circulating solutions.

Conclusions.—We have seen that the ores were deposited in fissure veins by ascending solutions. The conclusion follows that the ore deposits should continue downwards. Their character may change and the mineralization will probably be confined to narrower limits, but there can be little doubt that the ore deposits will go down; Weaver estimates to 1,000 ft. below sea level.[33] Such a definite limit seems scarcely

[33]C. E. Weaver. Index Mining District. Bull. 7 Wash. Geol. Surv., 1912, p. 70.

warranted, but the depth surely is not excessive. In other parts of the world, experience shows that fissures are persistent to such depths as the economics of mining has warranted following them. The same can be predicted for the Berlin Mining District. Values will continue in depth as far as the costs of mining will permit them to be followed.

It seems probable that the character of the ore will change. This has been the case in neighboring regions and is also a fairly general rule. The tendency at Monte Cristo is to change in depth to arsenopyrite and pyrite, with increase in gold and a decrease in copper and lead. It is confidently predicted that a similar history will be met in the Berlin mines. A loss of the lead and copper values, unless attended by a considerable increase of gold, will be a serious factor in handling the ore, but this loss will in part be counterbalanced by a decrease in the refractory character of the ore, due to admixture with blende. Those mines, such as the Grand Central, where pyrite alone occurs, should not experience any marked change with depth.

Since the ore is due to circulations set up by the Snoqualmie granodiorite batholith, future prospecting will be most successful in this terrane or in those immediately adjacent.

Part 3. Mining Properties.

Cleopatra.—The Cleopatra mine (J2) is connected with Berlin by 4,000 ft. of aerial tram and 7½ miles of puncheon road. Early shipments brought $132 per ton, and the several companies who have successively leased the property have shipped considerable ore.

The country rock is a biotite granodiorite, and the ore occurs in parallel, leached fissure zones. There are three sets of veins, often several veins comprising a set. The most strongly mineralized set is the northwest (40°). According to Ingalls, three parallel veins of this set at 90-ft. intervals are known, and one of these veins has been explored 700 ft. horizontally and 300 ft. vertically. Other vein systems strike N.38°E. and N.80°E., but members of the last or "formation vein" are poorly mineralized, though the mine was originally laid out along this system. Ore is developed in lenses in the

northwest system, which swell to 3 ft. and shrink to 6 in. thickness. It is an antimonial silver ore carrying about $4 per ton in gold. Shipments assaying well over 200 oz. of silver have been made, and the silver is known to be associated with stibnite and galena. The sulphides are extremely finely

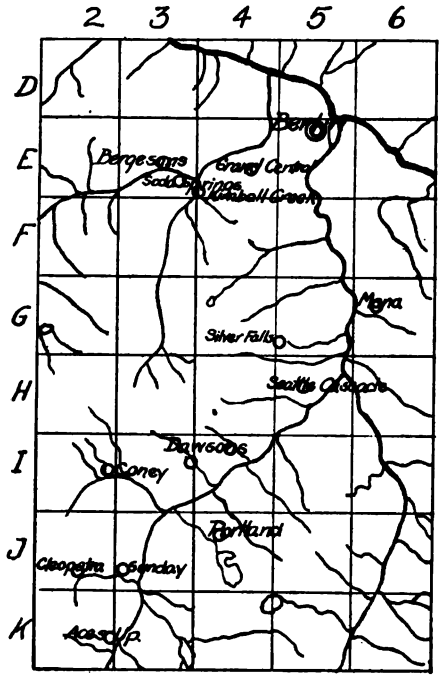


Fig. 11. Index Map of Berlin Mining District.

divided and the ore does not seem to be of a nature which would allow mechanical concentration. It is treated by smelting.

Drifts totalling 1,700 ft. have been driven, which, in connection with winzes and slopes, makes the Cleopatra the best developed mine of the district. In conclusion, the writer believes this property to have a future. However dismal the past record of looting, and however discouraging the disregard of economic or scientific policies may have been, it may fairly be said that the vein system is of proved value.

Coney.—The Coney (I 2) was very active until litigation resulted in closing the property. An electric equipment was

installed on Coney Creek to furnish light and power for driving some 1,650 ft. of 7×7-ft tunnel. This adit was electrically lighted, had an electrically driven ventilation plant, and used gravity haulage.

Fig. 12. Coney Mine, with steep dipping vein. Rock, granodiorite.

A leached fissure zone varying in width up to 40 ft. lies between granodiorite walls and is filled with a sericitized mass containing an abundance of disseminated pyrite. At the surface, the vein shows 3 ft. of rich sulphides in a well defined zone dipping S.80°. (Fig. 12). The ore consists of heavy sulphides in about the following proportions: Blende, 50%; galena, 20%; pyrite, 30%.

At 775 ft. from surface the tunnel deviates 45° from the trend of the vein (N.45°E.) and the remaining 875 ft. is practically a tangent driven, seemingly without purpose, into the country rock. At 1,175 ft., a narrow vein, 3 ft. between walls, is crossed (N.83°E.). In this vein, lime carbonate is precipitating on the tunnel floor and as stalactites (Fig. 9). It

is difficult to account for this carbonated water at so great a depth, unless it comes from below. The granodiorite is low in lime and could scarcely supersaturate water in the anamorphic zone. On the other hand, as a last stage in syngenetic vein formation, such a saturation with the product of mag-

Fig. 13. Portland Mine. Looking across valley of the West Fork of Miller River. Rock, granodiorite.

matic emanations is to be expected, and offers corroborative evidence of the primary nature of the ore deposit.

Portland.—(Fig. 13). This prospect has almost no development, and is mentioned only because the excellent surface showing gives promise of valuable mineralization. The fissure vein, between granodiorite walls, is 18 ft. wide, bears N.73°E. and dips S.75°. Ore occurs in pockets in the entire zone, but is richest close to the walls.

Little Una.—The Una group, in its present stage of development, is chiefly interesting for its mineralogy, though since the mineralogy indicates dying pneumatolytic action, it is

suggestive of mineable ore deposits. It is situated on Miller River (I 4), 5½ miles from Berlin. There are two places of development. The first of these, called the Una, has 130 ft. of tunnel, winding around in a tourmaline deposit. This mineral was thought to be an ore of iron and some of it has been sacked for shipment. It occurs in prismatic, shiny, black crystals in a vein deposit about 20 ft. wide, between granodiorite walls, and near the surface it is stained with malachite. The occurrence of tourmaline in such quantities is of particular interest because of its known associations with valuable mineralization.

Dawson's.—This is an interesting prospect on which 600 ft. of drift in a 12-ft. leached zone (N.70°E., S.80°) has exposed a strong vein of heavy sulphides. The ore is essentially silver-lead and yields an average of $60 per ton. Some blende and a small amount of chalcopyrite occur, and gold in greater or less amount seems to be associated with the arsenopyrite and pyrite. The following assays are given by Mr. Dawson:

Gold	Silver	Lead	Copper	Value	Assayer
0.07 oz.	27.6 oz.	30.1%	3.12%	$50.09	C. F. Bogardus
0.10	25.0	33.0	1.6	54.00	A. Stalberg
3.37	10.0	5.0	..	78.50	A. Stalberg
0.04	30.0	41.0	2.52	59.20	Falkenburg & Laucks
4.06	4.0	3.5	0.4	87.10	Falkenburg & Laucks

Seattle-Cascade.—This property is situated on Miller River (H 4, 5), 4 miles from Berlin. Work was done on the upper tunnel, whence a few carloads of rich lead ore were trammed down. Later a compressor was installed and about 800 ft. of adit driven to develop the known vein at an elevation some 700 ft. lower than where first explored. In later years the heavy machinery of a concentrating mill was installed, but never operated. In both the lower and the upper tunnel the vein strikes N.48°E., S.60°, and it lies in a leached fissure zone some 15 ft. wide between biotite granodiorite walls. The heavy, well banded sulphide ore is in general of about the following composition: Blende, 55%; galena, 20%; pyrite, 15%; arsenopyrite, 5%; quartz, 5%.

Mona.—The Mona group is located in G 6, 2½ miles from Berlin on the east side of the Miller River valley. The country rock is a grey, massive, tufaceous, andesite felsite, belonging to the Keechelus series. The zone of mineralization is about

40 ft. wide, strikes N.80°W. and stands nearly vertical. The ore is a sulphide carrying copper and zinc. It is beautifully irridescent and occurs in segregations and veinlets in the leached felsite. Apatite is present in considerable amounts. The ore is low grade, but appears to be present in sufficient quantity to warrant further development.

Fig. 14. Paragenesis of Minerals, Grand Central Mine. (C, calcite—latest. Q, quartz. S, sericite—oldest.

Grand Central.—This property, in E 4, is located on Money Creek, one mile from Berlin. In the lower workings 1,200 ft. of tunnel has been driven and at present a concentrating mill is being installed. The country rock belongs to the Keechelus andesitic series, into which has been introduced, in narrow veinlets, quartz, pyrite and calcite. (Fig. 14). These minerals seem to be later than the leaching because they are perfectly fresh. The mineralized zone, about 40 ft. wide, follows a fissure which strikes N.83°E. and dips steeply south. Mineralizing solutions are still circulating, as evidenced by recent deposition of calcite. It is understood that the ore averages about $4 per ton, and it seems probable that the property will not be troubled for lack or ore.

OCCURRENCE OF AMAZON STONE

AT NORTH WHITE PLAINS, N. Y.

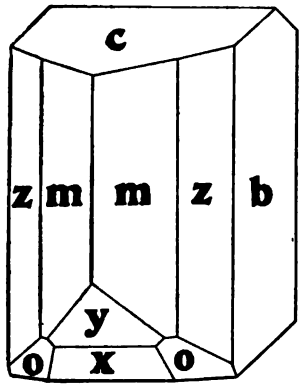
BY FREEMAN F. BURR.

To supply broken stone for the concrete of the Kensico dam, of the New York City water supply system, a quarry was opened several years ago in a large mass of pink gneissoid granite, part of the intrusive known to local geologists as the Yonkers gneiss. The rock in general here, as elsewhere, is a notably acid granite; the color is due to an abundant pink feldspar, sometimes normal orthoclase and sometimes microcline; the foliated appearance arises from the orientation of scales of biotite. Plagioclase feldspars occur, and occasionally the biotite gives way to hornblend; there are also a number of minor accessories.

For the most part, the rock is good clear material, quite uniform in character and with joints sufficiently separated to afford plenty of blocks large enough for the purposes for which the quarry was opened. Here and there, however, are found more or less definite dykes, stringers, and irregular masses differing noticeably from the rest of the rock. On close examination it is found that in most cases these are not sharply marked off from the granite, but are rather the result of a gradual change in character, either by increase in the size of the grains or by variations in the relative amounts of the constituent minerals; in either case, the change is accompanied by loss of foliation. In other words, these irregularities seem to be due to activities within the rock itself, (aqueo-igneous), rather than to injection from without.

In most of the cases above described, there seems to have been little opportunity for the free formation of crystals with regular outlines, the conditions in this respect having been much the same as in the general mass of the granite. There are, however, certain irregular masses of pegmatite, of comparatively limited extent, in which are found crystals of green microcline, or amazon stone, and these are in part remarkably well bounded; in this case it seems evident that the pegmatite partially lines cavities more or less lenticular in form, and that the microline has had an opportunity for free

development out into the open spaces. The pegmatite here, as in the other cases, is not sharply separated from the granite, but has all the appearance of an outgrowth from it, due doubtless to the special activity of various mineralizers. Its general composition is practically the same as that of the whole mass. It contains large amounts of quartz, varying from white to smoky, much pinkish feldspar, considerable plagioclase (chiefly albite), and large plates of biotite. Good-sized garnets are occasionally noticed, and irregular grains of greenish or violet fluorite, sometimes an inch or more in diameter.



By far the most striking mineral is the amazon stone, both because of its color and because of the fact that it has formed well-bounded crystals which stand out sharply from the wall of the quarry where the blasting has exposed the cavities in which they grew. The color varies from a faint tinge to a good bright green (in every case streaked with fine white lines), the color evidently being intimately associated with the free growth of the crystals, as it is almost entirely confined to the outer portions of the free ends. The basal cleavage surfaces almost invariably show a gradual transition from a pinkish center to a bright green rim varying in thickness with the size of the crystal. Microscopic examination of thin sections shows the crystals to be microcline with an intergrowth of albite, (the white lines already mentioned); it then is actually perthite.

The crystals vary in size from a fraction of an inch to 7 or 8 in. diameter. They show many variations in relative length of axes, and in the development of faces. Most of them have well developed terminal faces only at the free end. The other termination and some of the side faces are lost by the interference of imperfect crystals of other minerals, frequently albite. Occasionally it is possible to find an individual with

two good terminations; I have one small crystal with all its boundaries nearly perfect.

The amazon stone has been limited, so far, to a few cubic yards of rock in one part of the quarry; at present it is exposed in two places within a few yards of each other. There is, however, no apparent difference between the granite just there and in other places, and it seems probable that in the course of time other cavities will be opened.

BOOK REVIEWS.

Tunnelling. By Eugene Lauchli. Cloth; 6x9 in.; 238 pp.; 197 illus. McGraw-Hill Book Co., New York. 1915. Price $3.

This is one of the most satisfactory small books on the subject we have seen. It makes no attempt to cover exhaustively the correlated arts of drilling and blasting, each of which might fill a book by itself, but relates to the broader features of tunneling. The book has a refreshing air of originality, most of the data being taken from the author's own observations, with only a few compiled from published sources. Most of the examples are railroad tunnels or those for water supply; nothing is said about mine tunnels.

The author is to be complimented for omitting a great mass of minute details, and for presenting the deeper engineering features of the problem. The chapters on rock pressures and temperatures, and strength of linings, are particularly valuable. The importance of careful geological exploration is emphasized throughout, since the art of tunnelling consists mainly in the resisting of geological forces. The examples are wisely chosen, largely from European tunnels, and are presented with sufficient detail as to conditions encountered, methods adopted, cost and speed of operation, to render them of great value.

From the literary point of view, the constant confusion and misuse of "overlie" and "overlay" is to be regretted. The selection of type for headings and sub-headings is open to criticism. An engraver's error robs Figs. 102 and 103 of their significance. In our opinion the book is rather more valuable to a practicing engineer than to a student. E. K. J.

An Introduction to Mining Science. By John B. Coppock and G. A. Lodge. Cloth; 4x6 in.; 230 pp.; 102 figs. Longmans, Green & Co., 1915. Price $0.60.

The title of this little book is faulty, because the art of mining will never be a science, and it is misleading, because the book refers to only a few features of coal mining, namely, the occurrence and behavior of gases and other inflammable substances, the effects of heat, and the precautions against explosions. This restricted field, however, is covered quite satisfactorily, the authors evidently having in mind the education of practical miners and young men in the British coal fields. The language is popular in style, the illustrations are clear, and the manner of presentation is good, being based

on about equal parts of laboratory experiments and commonplace observations. The former are of the kind usually performed by beginners in physics and chemistry in America. Every chapter contains paragraphs pointing out the practical bearing of the preceding observations and experiments on the practice of coal mining, and concludes with a few suggestive questions. We believe the book will be useful in its field, but will not be a valuable addition to the library of an advanced student of engineering. E. K. J.

ALUMNI NOTES.

1895. Henry W. Durham, C.E., recently chief engineer of highways, Manhattan Borough of New York City, announces his association with Percival R. Moses, E.E., for the practice of highway and municipal engineering of all kinds. Address: 366 Fifth Ave.

1900. John A. Fulton, E.M., of Melones, Cal., announces the birth of a daughter on June 12, 1915.

1902. Edward F. Pelton, E.M., is superintendent of the Burro Mountain Copper Co., at Tyrone, N. M.

1902. Thomas T. Read, E.M., was appointed chairman of the department jury of awards in mining and metallurgy at the Panama-Pacific Exposition, and also represented that department on the Superior Jury, which convened in June to make final awards.

1905. H. L. Mead, E.M., has returned to New York after a professional engagement in Idaho. Address: 122 East 36th St.

1906. A. B. Young, E.M., was promoted on May 1 from his position as head of the testing department to be superintendent of blast furnaces of the International Smelting Works, Tooele, Utah.

1908. Andrew W. Newberry, Met.E., of Los Angeles, started in May for Central Alaska on professional work which is expected to last until next winter.

1909. G. M. Helmrich, E.M., and S. Melitzer, E.M., '11, with the Braden Copper Co., Chile, are taking a vacation trip to Spain.

1909. D. B. Steinman, C.E., Ph.D., has resigned his professorship of civil engineering at the University of Idaho and is now in charge of the design of a long-span continuous bridge over the Ohio River, for the C. & O. N. Ry. He was married June 9 to Irene S. Hoffmann, of New York. His "Plain and Reinforced Concrete Arches", a translation of a German work by J. Melan, was published by John Wiley & Sons last March.

1909. W. B. Mucklow, E.M., is in the Nevada Consolidated Company's concentrator at McGill, Nev.

1909. Donald G. Miller, E.M., is on the engineering staff of the Burro Mountain Copper Co., Tyrone, N. M., having charge of the township operations.

1909. Preston E. Locke, E.M., is shift foreman at the Braden mine, Rancagua, Chile.

1909. G. B. Holderer, E.M., returned from Chile for a visit to New York in May, 1915.

1909. G. M. Richards, E.M., has returned to New York from a two-years' trip into central Africa, and is now en-

gaged in preparing his report for the Belgian government.

1910. F. H. Hayes is head of the geological department of the Detroit Copper Mining Co., at Morenci, Ariz. T. B. Counselman is also at Morenci.

1911. Frank A. Ayer, E.M., foreman of the Rogerson & Yankee mine of the Detroit Copper Co., Morenci, Ariz., visited New York in May.

1912. J. M. Lovejoy, E.M., formerly at Chuquicamata, Chile, is now in China, making geological studies for the Standard Oil Co.

1912. D. G. Hubbard is chief sampler for the Detroit Copper Co., at Morenci, Ariz.

1913. G. J. Schattinger, E.M., and E.A. Suverkrop, E.M., are at Chuquicamata, Chile. Address, via Antofagasta.

1913. A. H. Morrill, E.M., who is engineer with the Central Chile Copper Co., at Panulcillo, Coquimbo, Chile, visited New York in May, 1915, on a holiday tour. He will return to Chile via Canada, California, and New Orleans.

1913-14. Recent mining graduates of Columbia are strongly in evidence in Arizona. At Morenci are: D. G. Hubbard, on the geological staff of the Detroit Copper Co.; and W. R. Grunow, C. W. Eichrodt, H. E. Bird, and K. F. Hess, occupying positions with the different mines of the district. J. B. Kurz left Morenci in May to go to Miami. Others at Miami are C. E. Meissner, O. N. Rugen, and C. J. Mampel.

1914. C. F. Mampel, E.M., who has been situated at Morenci, Ariz., visited New York in May, 1915; on returning to Arizona, he took a position in the Inspiration Copper Company's concentrator at Miami.

1914. D. C. Hoyt, E.M., has returned to New York after spending about a year in geological work for the Vermilion Range Land Co., which is exploring the titaniferous magnete deposits in Cook county, Minn., north of Lake Superior.

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BASIC PRINCIPLES OF MINING COST*

BY JAMES R. FINLAY.

In the brief time at our disposal, I shall be able to call your attention to only a few simple matters, the influence of which on the cost of mining is, however, frequently overlooked even by experienced engineers.

The total cost of operating a mine can be divided into at least three independent items, namely: (1) labor, (2) power, (3) supplies. It is important to make this classification for two reasons: first, because the three items do not enter in the same proportions into the cost of operation at all mines; and second, because the variation in the cost for one item, from place to place, may not be in the same ratio as for another of the three items.

In general, the cost of mining in a given locality will vary with the expense and facilities for obtaining labor, power, and supplies. Of all the mining regions in North America, I believe that the most favorably situated is found in Western Pennsylvania. Between Pittsburgh and Lake Erie is a vast fertile country, capable of supporting a large population; food is abundant, climate excellent, and sociologic conditions are favorable. Hence labor is cheap and, what is of even greater advantage, can be carefully selected with a view to fitness. For power, the immense bituminous coal fields, and the areas yielding both oil and gas are close at hand. Finally, the district is surrounded and dotted with great manufacturing centers, whence mining supplies are available in great variety and at small expense of transportation.

*A lecture before a class of mining engineering students in the Columbia School of Mines, May 4, 1915.

When we seek to compare mining costs in so favorably situated a district with those prevailing in another part of the country, for example, Alaska, or the desert parts of Nevada, strict allowance must be made for the changed environment. In both the localities just mentioned, and in many others as well, labor must be imported, and it is not so easy to exercise discrimination in its selection. Furthermore, in a remote locality, food is often poor and usually expensive, and many of the ordinary comforts of civilized life, sometimes even the decencies, are wanting. These hardships must naturally be compensated, in the form of higher wages. The cost of power is likewise generally higher, because of the expense for transportation of fuel. In some favored localities, the supply of wood may suffice for a while, and in others hydro-electric power may be available, but the great majority of mines rely upon coal, and in many cases it will be found that the cost of transport exceeds that of mining the coal. Thus, coal which sells at Pittsburgh for, say, $1 per ton will cost $2.50 in the Lake Superior district, $4.50 in the Rocky Mountains, and as much as $7 or above in more remote districts. The same holds true of supplies, to the original price of which must be added cost of transportation by boat, rail, wagon, or mule-back. Since steel and dynamite, the two most used materials, are relatively high priced, the added cost due to transportation is proportionately less than in the case of coal.

As a concrete example of the preceding remarks, let us compare a mine in Southeast Missouri, with one in Nevada, in both of which districts I have recently been so fortunate as to gain first-hand experience; in both cases we shall estimate that the output is at the rate of 4 tons per man per day. In Southeast Missouri, labor (at $2.60 per day) costs 65c. per ton of ore mined and milled; power (coal selling at $2.25 per ton) costs 25c. per ton of ore; and supplies cost 15c. per ton of ore; total $1.05 per ton. Profit on this ore would then be about $1 per ton, out of which to deduct various general and interest charges. At a mine of the same character in Nevada labor (at $4.00 per day) would cost $1.00; power (coal at $6.75 per ton) 75c.; supplies (estimated at 20% higher than in Missouri) 18c.; total $1.93 per ton of ore, or $0.88 more than in Missouri. If the ore had the same market value, the

profit would be only $0.12 as against $1.00, and this difference would very probably be the deciding factor in determining whether or not to begin operations in the more remote district. In short, the extreme variability of operating conditions at different mines, and in different districts, must never be overlooked.

It has been said that mining engineers do not know how to figure costs, as a contractor would figure them. This is not exactly true, because all successful engineers really do know how to do it, and the wider their knowledge of operating factors, the less liable they are to make mistakes. As a rule, careless or ignorant computations result in underestimates. An excellent practice is for an engineer to put himself in the position of a contractor, personally responsible for a loss; cost estimates then cease to be academic questions.

The most fertile source of mistake in cost estimates is to assume that the data relating to a short period, possibly during a stage of most advantageous operation, are a true average over the whole life of an undertaking. It should be remembered that the cost of an enterprise includes everything that has to be done from start to finish. To illustrate, suppose a shaft has to be sunk in New York City. If a practical miner were asked how much it would cost, he would first inquire how hard the rock is, and would then figure the cost merely as a job of rock breaking, at so many feet per shift. A contractor, on the other hand, would include in his estimate the necessity for installing hoists, compressors, shops, and headgear, entailing maintenance, depreciation, and interest on the cost of equipment during the whole period of operation.

In comparing one mine with another, the physical characters of the ore deposits are no less important than their geographical situations, a feature of the problem which is sometimes carelessly overlooked by those who ought to know better, and often purposely disguised by those who have some nefarious purpose in view. How often have we heard promoters calmly assert that a gold-bearing vein in Georgia, for example, could be mined at the same cost per ton as at the Homestake or the Alaska Treadwell?

The importance of careful comparison of geologic conditions was forcibly impressed upon me about three years ago when I had occasion to examine a silver mine in New Mexico, at

which the cost of mining and milling was $8 per ton. The mine was controlled by residents of the Lake Superior district, who, reasoning from their immediate experience, thought that the cost ought to be reduced to $3 per ton, and wished to be informed why not. The reason is that a silver lode in New Mexico is not like a bed of copper rock or a basin of hematite in the Lake Superior region, and can not be mined in the same way. Actually, the Camp Bird mine, of Colorado, offers a much clearer analogy, in width of vein, character of mineralization, and occurrence of ore shoots, the latter constituting only 25 to 30% of the whole vein and necessitating a relatively great amount of exploration and development. The cost at Camp Bird is from $7 to $8 per ton. My Lake Superior friends failed to be impressd by my reasoning, and proceeded to capitalize and equip their mine on the assumption of $3 costs; they are now sorry they did so.

While a careless reasoning from analogy may lead to disastrous failure, as in the case just noted, on the other hand, if geologic conditions and working environment at a new locality be reasonably similar to those at an older and established mine, this fact offers a quick and serviceable means of estimating the probable working cost at the mine about to be developed. In fact, a simple comparison, provided that all conditions are closely parallel, or provided that allowance is made for divergent conditions, is much more useful, and accurate, than any amount of independent figuring.

In this connection, it is often possible to make use of certain formulas and standards of comparison which are not so well known as they deserve to be. Hamilton Smith, a distinguished engineer about 30 years ago, suggested the advantage of comparing mines on the basis of yield per unit of stoping area, and gave as his opinion that, with gold ore of good quality, no mine would be profitable which yielded less than $3 per square foot of stoping area, equivalent to $130,000 per acre. Applying this formula recently to a fairly profitable gold mine in Nevada, having a vein 1 ft. thick, of ore averaging $40 per ton, I was interested to observe, allowing 13 cu. ft. per ton, that the yield of that mine was almost exactly $3 per square foot of stoping area. Actual stoping width was about 4 ft. and profits were about 20% of the gross yield.

Smith's factor is important to bear in mind, regardless of other estimates of cost obtained by calculation, comparison, or otherwise, especially for checking overestimates of net profits. A mine alleged to yield net profits of 75% of the gross output should be approached cautiously, because such mines are very rare. The Goldfield Consolidated, for example, for considerable periods yields at the rate of $20 per square foot of the whole area of vein explored, not merely shoot or stoped area; yet the net profits of this mine for the past five years have averaged only 58% of the gross yield, under particularly competent management. On the whole, Smith's rule is a wise one to follow.

Some people are inclined to attach too much importance to "cost per ton", as though this unit possessed some sacred functions. It may often happen that some other unit, as Smith's yield per unit of stoping area, is more serviceable and relevant. Cost per ton is merely the value of the work that has been done on that ton, and may bear a very indefinite relation to the profitableness of the operation. As an extreme case, 1 ton of gold, worth $600,000, might be mined for $450,000, or 75% of its value, yielding a profit of $150,000. A ton of silver, worth $15,000 is mined at Cobalt for $6,000, or at $600 per ton of ore, assuming it to contain 10% silver; yet, rightly considered, this should not be called expensive mining. At Grass Valley, Cal., it costs about $5 to mine and mill 1 ton of ore; at the Michigan copper mines it costs only $1.25; yet applying Smith's unit, we find that the cost per acre of stoping area is nearly alike in these two places, namely $100,000 at Grass Valley and $70,000 to $120,000 in the copper country. In Southeast Missouri, the cost is almost exactly $100,000 per acre for mining and milling. We thus see that the really important factor is not how many tons are mined, but how much area must be excavated.

Finally, before making comparisons of cost, it is important to note the relative difficulties arising from different positions of an ore-body; it makes a great difference whether a deposit is horizontal, vertical, or inclined. A horizontal deposit is always the cheapest to mine because when the shaft is sunk, there is only one level, one shaft, one pump station. A vertical deposit requires many levels, each exploited separately, each

requiring a shaft station, and sometimes an independent pump station. Inclined deposits, if not steep enough for broken ore to slide, involve all the disadvantages of a vertical vein, with the added expense of handling ore in stopes.

Your professors have of course discussed the engineering aspects of this matter; I intended only, in conclusion, to emphasize the importance of careful scrutiny before attempting a comparison of working costs.

TABLES FOR THE DETERMINATION OF GEMS AND PRECIOUS OR ORNAMENTAL STONES WITHOUT INJURY TO THE SPECIMEN

BY ALFRED J. MOSES, PH.D.

The following tables were arranged for students taking courses in gems and gem minerals given by the writer in the Summer School of Columbia University. The classification chosen almost necessarily began with color (and play of color) as this character best utilized the existing practical knowledge of pupils, and despite the great repetition of *species* names caused thereby the color classification brings out well the trade names, which, for the most part, are based on color.

The tests used for the subdivisions in tables 1 to 10 (with the exception of the hardness, which is recorded but made subordinate) are exclusively tests which will not injure cut and polished stones. In a supplementary table the stones are given in alphabetic order and, as far as yet obtainable, the results of heat and solvents are recorded. In certain instances these are needed for confirmation.

In conducting the course the tests used in the scheme are first made upon known substances, and certain other tests which serve to fix the lectures in mind such as 6, 7, 8, 11a, b, c, etc., are also made.

For convenience, the entire series of tests is here stated, but detailed instructions are given only for those which figure prominently in the tables.

A. Tests of Supplementary Tables, and Crystallographic Tests

1. **Effects of Moderate Heat** (Not over dull red).—Place fragments of the stone in a hard glass tube closed at one end. Hold this end near a bunsen burner and heat to dull red. Note the changes of color, permanent or temporary, deposition of moisture or sublimates, glowing, etc.

2. **Effect of Blowpipe Heat.**—Blow a 1-in. blue flame with the blowpipe and direct the tip of the flame upon the point of a paper-thin fragment held in platinum forceps. The fragment must project beyond the forceps at least 1/16 in. and

better 1/8 in. Note the effect by examining the point with a lens before and after. Moisten the fragment with dilute hydrochloric acid, and again heat, noting whether the flame is thereby colored.

3. **Effect of Concentrated Hydrochloric Acid.**—With a glass rod place a single drop of acid on a smooth surface of the stone (or upon an object glass, adding a few particles of the powdered stone). Let this acid nearly dry, and examine under the microscope.

4. **Effect of Dilute Hydrofluoric Acid.**—Dip the stone in melted paraffine and mark a cross or other convenient shape through the paraffine above some unimportant face. Immerse for 1/2 hour in the acid (1 c.p. acid and 2 water), remove, wash, and clean off the paraffine. If the cross shows, then etching has taken place.

5. **Bead Tests.**—The coloring effects of iron, manganese, chromium, titanium, and copper, on beads of borax, salt of phosphorus, and soda.

6. **Recognition of Crystal Symmetry and System.**

7. **Determination of Cleavage.**

8. **Identification of Natural Crystals by Angles and Symmetry.**

9. **Determining Specific Gravity.**—After preliminary practice in approximate determination of specific gravity: (a) by hand, (b) by specific gravity liquids, (c) by diffusion column, determinations are made with a delicate balance accurate within at least one-tenth milligram. The result should be correct within 0.01 or 0.02. A small wooden bench to span the scale pan and a platinum spiral to hold the stone are required. Make three weighings:

W = Weight of the stone.

S = Weight of the spiral when suspended from the end of the balance frame and immersed in the distilled water. (This weight may be determined once for all).

W_1=Weight of the stone and the spiral suspended in distilled water.

$$\text{Then, Sp. Gr.} = \frac{W}{S+W-W^1}$$

Usually no correction need be made for temperature. Greater speed and, if proper corrections for temperature are made, equal or greater accuracy are obtained by substituting for distilled water benzol or toluol, which have less surface tension than water. The result obtained by the above formula must then be multiplied by the specific gravity of the benzol or toluol for the temperature at which the weighing was made.

10. Hardness.—The hardness may be determined with care on the girdle or some inconspicuous facet. At worst it may necessitate a repolishing of the facet. While, strictly, hardness is the resistance of a smooth surface of the substance tested to the making of a scratch by a pointed fragment of known hardness, the procedure may conveniently be reversed, and the power of an edge of the cut stone to make a scratch upon a polished surface of known hardness be the fact determined. The jewelers file and conical pencils made of the test members of the scale are much used.

B. Tests of the Principal Tables.

11. Preliminary Tests with the Microscope.—

Learning to centre and focus.

Determining plane of vibration of lower nicol.

Determining value of one division of fine adjustment.

12. Determining Single or Double Refraction.—Nearly fill "cup" with monobrom-napthalene and insert the stone with the table face up. Using moderate power objective, focus with upper nicol out, then push in nicol and rotate the stage. The stone may be:

(a) Doubly refracting; the field dark at intervals of 90°, and elsewhere illuminated.

(b) Singly refracting; the field dark throughout rotation, both for this position of the stone and for any other.

(c) Too opaque or of too confused (aggregate) crystalline structure to give either of above tests.

It is to be noted that "local" double refraction, varying in different parts of the stone, may occur as a result of strain in singly refracting substances.

Determining Index of Refraction for the D-line of the Spectrum.—Liquids, glasses, and isometric crystals have each one index of refraction for the D-line whatever direction of trans-

mission is used. Stones cut from uniaxial (tetragonal or hexagonal) crystals give two indices of refraction for each direction of transmission (except one); one of these is constant whatever the direction, the other varies between limits. In one direction these stones are singly refracting. Stones cut from biaxial (orthorhombic, monoclinic or triclinic) crystals give two indices for each direction, and there is no constant index.

13. **Index of Refraction by a Refractometer.**—After practice in determining: (a) index of a liquid, (b) index of a singly-refracting solid, such as glass, proceed as follows for a cut stone: Place a drop of liquid of known index of refraction on the centre of the glass of the instrument; on this place the largest face of the stone. Admit light from below, and use the sodium flame. If only the limit line for the liquid is found, repeat with a liquid of higher index of refraction.

Carefully revolve the stone, keeping the same face in contact with the glass. If the revolution produces no movement in the limit line or lines, the value is read and the note made that the stone is probably either amorphous or isometric. If the revolution produces obvious movement, and two lines are obtained, both are read *when at their greatest distance apart.* It should be noted whether one (uniaxial) or both lines (biaxial) move during the revolution.

14. **Index of Refraction by the Microscope.**—Set the fine adjustment screw near the upper part of its motion, and place a minute spot of ink on an object glass. Centre this spot, and cover it with the table facet of the stone, and focus upon the ink spot *through the stone* as sharply as possible. (The stone increases the focal length of the microscope an amount dependent on the thickness of stone interposed and its index of refraction.) Remove the cut stone without disturbing the object glass; then using the fine adjustment only, and keeping count of the number of rotations, lower the objective until the spot of ink is again in focus. Measure the thickness of the stone with a micrometer gauge and denote this thickness by T, and the displacement or change in focal length by D.

$$\text{Then: Index} = T \div (T - D).$$

If no face has been cut parallel the table face (culet) two

faces may have been cut nearly parallel and the ink spot can be seen through both at once. Sometimes, if the faces come to a point, a drop of oil at this point will support a thin cover glass and bring the spot into view. In this case the D value includes the focal change due to the cover glass; its thickness must therefore be added to T; the correction is approximate unless glass and stone have same index.

15. Pleochroism of a Cut Stone with the Microscope.—Place the stone in the metal cup, cover it with monobromnapthalene. Focus with the upper nicol out; push in upper nicol and rotate the stage until the field is dark; push out the upper nicol and note the color of the stone. Rotate stage 90° and again note the color. These positions give the maximum difference in color for the direction of transmission. Whether a difference in color (pleochroism) was noted or not, tip the stone into some notably different position and repeat the test. If in neither direction pleochroism is observed, it either does not exist or is very weak.

16. Pleochroism in Cut Stone with the Dichroscope.—Hold the stone close to the square orifice. Use reflection from a sheet of white paper as the source of light, and rotate the instrument until the two images are of the same color. Midway between two such positions the colors differ most. Whether pleochroism is shown for this position or not, place the stone in a second notably different position and again try for the limit colors.

C. Special Optical Tests of "Birefringence," Uniaxial vs. Biaxial, and + or — Optical Character.

These tests are recorded under each table for the middle division (Transparent, doubly refracting). For instance, Tourmaline, Uni (—) .011 means that tourmaline is uniaxial, optically negative, and that *the maximum* possible difference between the indices of refraction for the D-line is 0.011.

17. Birefringence with a Refractometer.—In material as thick as even a small cut stone the usual method of estimation by means of the so-called interference colors is not applicable, and the available methods are very approximate.

Determine the values of the limit indices as in No. 13; their difference will approximate the birefringence, but its actual

value is probably higher, as only in certain planes would this maximum value be obtained. An approximation can also be made if a little powder of the stone can be obtained[1]. For stones equal of thickness, an examination of the apparent width of an edge seen through the stone gives a suggestion of the birefringence. Thus, equal thicknesses of titanite, 0.12, chrysolite, 0.036, tourmaline, 0.02, would show edges with apparent breadth relatively 6:3:1.

18. **Uniaxial vs. Biaxial with the Microscope.**—The uniaxial vs. biaxial character is suggested by the behavior of the limit lines in determining the index of refraction with the refractometer as described in 13. With the microscope and in certain directions only, characteristic so-called interference figures may sometimes be obtained as follows:

Place the stone in the "cup" containing monobrom-napthalene. Use the high-power objective and a convergent lens below the stage. Focus with the upper nicol out. Insert the upper nicol and, removing the eyepiece, look down the microscope tube.

Repeat this for different directions by changing the position of the stone in the cup.

Much better results are obtained by substituting for the convergent lens and the high-power objective two special lenses which yield the interference figure when the lenses are as much as an inch apart. The search for the "proper direction" is also greatly helped by devices for tipping the crystal while still immersed in the liquid. Both the special lenses and the tipping devices are provided in Prof. Klein's[2] rotation apparatus designed as an attachment to the larger Fuess goniometers.

Uniaxial Interference Figure.—A dark cross, the arms of which retain fixed directions during the rotation of the stage. There may also be a number of colored circles around the center of the cross.

Biaxial Interference Figure.—A black cross, one arm of which is usually sharper and more distinct than the other. If the section is turned, the dark lines seem to dissolve into hyperbolae, the branches of which rotate in the opposite direction to the rotation of the stage and the convex side of each

[1] "A Scheme for Utilizing the Polarizing Microscope in the Determination of Minerals." A. J. Moses, School of Mines Quarterly, vol. 34, p. 305.
[2] C. Klein. Sitz. d. Ak. Wissen. Berlin. 1895. p. 91.

is always toward the other branch. If any color is shown it is in curves around two points through which the sharper arm of the cross passes. These curves are not circles, and there is no change in their shape during rotation of the stage. Sometimes even the first ring will surround both axes.

19. Optical Character.—The test for index of refraction (12) will sometimes prove the optical character of a uniaxial stone.

(+). The constant index is less than the varying index.

(—). The constant index is greater than the varying index. No corresponding test exists for biaxial crystals.

The interference figures, as modified by a mica plate or a quartz wedge, furnish more generally used tests.

20. Determination of the Axial Angle.—The measurement of the angle between the optic axes requires that the plane containing these axes be perpendicular to the axis of rotation and that the nicols be crossed diagonally to the axial plane.

With the Klein rotation apparatus the adjustments can be made. If then a complete rotation is made and the readings recorded at which the four black hyperbolae are tangent to the cross-hair, the axial angle will result as follows. Subtract the consecutive readings a, b, c, d, thus, (a—b), (b—c), (c—d), (d—a), securing four angles. Denote the larger angles by X and X′, the two smaller by Y and Y′; then if the true angle is 2V,

$$\text{Tangent } V = \frac{\text{Sine } \frac{1}{4}\ (Y + Y')}{\text{Sine } \frac{1}{4}\ (X + X')}$$

21. Synthetic vs. Natural Corundum.—Whenever a stone is determined to be corundum, the question whether it was made by nature or by man must be determined. In chemical composition and crystalline structure the two are identical. They are related in same manner as natural and artificial ice. The essential differences rest upon the method of growth, the cavities and inclusions, and the cooling.

To distinguish, place the stone in the metal cup with a glass bottom, cover it with monobrom-napthalene, hold over white paper and look through, tipping the stone into various positions. Place the cup on the stage of the microscope and repeat the examination with a low or moderate-power objective,

focussing not only on the surface of the stone, but at all depths. The observed differences will be:

SYNTHETIC STONES.

Growth layers are parallel to a curved "top" shaped "boule," hence for any variation in coloring matter, *curved bands* usually best seen in the cup with naked eye or a very low magnification. If approximately straight, not parallel to extinction directions unless by pure accident.

Cavities and Inclusions.—Round black looking cavities filled with air are *practically always present.* (The blackness due to the relative indices of refraction of air and corundum). Cavities sometimes pear shaped or drawn out as if parallel to the flow of fused material. Liquid inclusions are impossible; included microscopic crystals are unknown.

Rapid cooling of the "boule" produces strain which causes frequent splitting parallel to the length, and furthermore often causes a series of rifts or cracks in approximately parallel position, often starting from a facet.

Direction of Cutting.—Owing to the varying position of the optic axis and to the longitudinal splitting of the boules, the table face is rarely if ever perpendicular to the optic axis; hence viewed in that direction is not pure colored but dichroic and does not yield interference figure.

NATURAL STONES.

Growth layers are parallel to the faces of a crystal; hence variations in coloring matter will as often be entirely irregular or else in straight lined bands parallel in series. Moreover, these bands will often be parallel to the directions of extinction.

Cavities and Inclusions.—The cavities are usually angular (negative crystals) and frequently contain liquids with a comparatively narrow black border and often a little central bubble. In what may be parting clefts there are frequently parallel microscopic needle crystals. There are rarely, if ever, the series of irregularly shaped crevices so common in synthetic stones.

Direction of Cutting.—Usually the table face is perpendicular to the optic axis, this giving the purest colors. If, then, perpendicular to the table face, or nearly so, there is obtained

an interference figure and no diochroism it is strong proof of a natural stone.

22. **Detecting Doublets.**—Hold with the forceps with the supposed joint vertical and dip into an opaque cup containing liquid. The color will thereby be restricted to the colored layer. A brilliant surface of contact, due to total reflection, may also appear.

Key to Tables.

(Each of three divisions in each table is arranged in order of specific gravity).

With Internal Light Effects

1. PLAY OF COLOR, CHATOYANCE, OPALESCENCE, ETC.

Without Internal Light Effects

2. COLORLESS OR WHITE OR PALE.
3. VIOLET.
4. BLUE.
5. GREEN.
6. YELLOW.
7. BROWN.
8. RED.
9. BLACK.
10. **Supplementary Tables.**

General Directions

The tests are to be made as described in the preceding pages.

In the specific gravity test, allow a margin of 0.02 on either side; that is, for a determination of 3.26 assume that the possible value lies between 3.24 and 3.28.

In the column "Indices of Refraction" note that the indices given are limit values for many specimens, not for one specimen. The birefringence is not necessarily the difference between the given indices but between the indices of any one specimen.

1. With Play of Color, Chatoyance, Opalescence, or other Internal Light Effects.

TRANSPARENT OR VERY TRANSLUCENT.

	Specific Gravity	Name	Usual Colors	Indices Refraction	Hardness	Other Distinctions
Singly Refracting.	1.06-1.08	**Amber**	Dark brownish red	1.54	2-3	Blood red, blue and green fluorescence
		Sicilian	.....	.....	.....	Transparent to X rays
	2.1 -2.2	**Opal**	Usually milky	1.41-1.45	5.5-5.6	Often fine crevices, refilled by other opal
		White opal	White, bluish, yellow, light tints	.....	.....	Beautiful play of delicate colors
		Fire Opal	Brownish red to orange or honey yellow	.....	.....	Fire like reflections. Not milky
		Black Opal	Dark gray, blue, nearly black	.....	.....	Brilliant varying colors. Often broad flashes
		Girasol	Colorless to bluish white	.....	.....	Wave of blue light
	2.5 -2.6	Obsidian	Dark Smoky	1.5	5.5	Golden green schiller
	Varied	**Glass**				
		Goldstone	Reddish brown	.....	5.	Spangles of copper
		"Opal"	.....	.....	.....	Play of colors due to etching. Surface effect only.
		"Pearl"	.....	.....	.....	Etched or backed and filled globes of glass. Minute holes with rounded edges. Iridescent. Drop of ink on outer surface reflected from inner
Doubly Refracting.	2.55-2.58	**Moonstone**	Colorless or gray	1.52-1.53	6-6.5	Internal milky blue cloud. Soft pearly tints
		Peristerite	White or gray	.....	.....	Pigeon blue reflections
	2.65	Quartz	.....	1.544-1.553	7	Vitreous lustre, no fire. Rotates plane polarization
		Rainbow Quartz	Colorless	.....	.....	Prismatic colors internally due to fine cracks.
	3.6	Cyanite	Sapphire blue or asparagus green	1.7 -1.73	5-7	Changing lustre. Somewhat chatoyant Pleochroic
	3.68-3.78	**Chrysoberyl**	.....	1.74-1.75	8.5	
		Cymophane or Cats Eye	Yellow, green brown	.....	.....	Pleochroic, Brilliant lustre. Chatoyant with fine sharp line of light which floats over surface as stone is moved
	3.9 -4.1	**Corundum**	.....	1.76-1.77	9.	
		Star ruby, star topaz, star sapphire	Red, yellow or blue shades	.....	.....	Six rayed light-star. Pleochroic
		Oriental Girasol	Red, yellow, blue shades	.....	.....	Wave of light, "Chatoyant," Pleochroic

OPAQUE OR TRANSLUCENT

Failing to Give Tests for Single vs. Double Refraction

2.31	Gypsum	.....	1.52-1.53	2.		
	Satin Spar	White, brown	.....	.....	Chatoyant.	Silky lustre
2.5 -2.6	Serpentine	.....	1.52-1.54	3-4		
	Satelite	Dull green	1.54	.....	Chatoyant.	Fibrous
2.58-2.64	Elaeolite	Greenish	.....	.....	Chatoyant.	Lustre greasy
2.65	Quartz	.....	1.54-1.55	6.5-6 7		
	Cats Eye	Gray, greenish	.....	.....	Chatoyant.	Included greenish fibres
	Tigers Eye	Brownish yellow or artificially colored	.....	.....	Chatoyant.	Included yellow fibres
	Falcon Eye	Dark blue	.....	.....	Chatoyant.	Included blue fibres
	Aventurine	Green, red, gray	.....	.....	Spangled.	Included scales
	Star	Colorless, pink	.....	.....	Six rayed	light star
2.6 -2.7	Feldspar	.....	1.52-1.54	6		
	Sunstone	Red, gray, green	.....	.....	Spangled.	Included scales
	Labradorite	Gray	.....	.....	Brilliant	changing colors
2.65-2.68	Pearl	White, pink, black, yellow	1.48-1.66	4	"Nacre"	or pearly lustre
2.72	Calcite	.....	.....	3		
	Atlas Spar	White, blue, green, red	.....	.....	Chatoyant.	Silky lustre
	Lumachelle	Gray or brown	.....	.....	Shell marble	with fire like flashes
3.1 -3.3	Enstatite	Greenish, brownish	1.66-1.67	5.5	Changing	lustre
3.4 -3.5	Hypersthene	Black or nearly	1.69-1.70	6	Bronze or copper	red by reflected light or spangled with brookite
3.9 -4.1	Corundum	.....	1.76-1.77	9		
	Adamantine Spar	Brown, gray	.....	.....	Chatoyant	

2. Colorless, White, Pale Gray, or Extremely Pale Tints.

(This list may be considerably enlarged by including unused colorless varieties of gem stones.)

TRANSPARENT OR VERY TRANSLUCENT.

	Specific Gravity	Name	Color	Indices Refraction	Hardness	Other Distinctions	
Singly Refracting.	3.52	**Diamond**	Colorless or light tints of yellow green, blue, brown	2.417	10	Characteristic Brilliant lustre and fire or play of color. Transparent to X rays. Often phosphorescent	
	3.6-3.63	Spinel	Colorless	1.72-1.73	8	Brilliant vitreous lustre. Little fire. Not electric by friction	
		Glass	.....	1.5-1.8	5 approx.		
	2.4-2.6	Crown	.....	.....	.....	Glassy lustre	
	3.1-3.9	Flint	.....	.....	.....	Glassy lustre	
	3.5	Strass	.....	.....	.....	With considerable "fire"	
Doubly Refracting.	2.65	**Quartz**	.....	1.54-1.55	7	Uni.(+).01	Glassy. In one direction rotates plane of polarization
		Rock Crystal	Colorless				
		Pale tints	Pink, yellow, etc.				
	2.69-2.75	Beryl	Faint blue, green, or yellow tints	1.57-1.58	7.5	Uni.(—).006	Brilliant in artificial light
	2.84	Beryllonite	Colorless	1.55-1.56	5.5	Bi.(—).009	Brilliant lustre, little fire
	2.9	Datolite	Colorless	1.63-1.67	6.	Bi.(—).044	
	2.95	Phenacite	Colorless	1.652-1.667	7.5-8	Uni.(+).016	Brilliant lustre, considerable fire in artificial light
	2.96	Danburite	Colorless	1.635	7+	Bi.(—).004	
	3-3.02	**Tourmaline**	Colorless or pale	1.62-1.64	7+	Uni.(—).02	Electric by heat or friction Nearly opaque to X rays
	3.17-3.2	**Spodumene**	Faint yellow or pink	1.66-1.68	6.5-7	Bi.(+).026	Very brilliant. Phosphorescent with ultra violet and radium
	3.5-3.6	**Topaz**	Colorless or faintly blue	1.61-1.62	8	Bi.(+).008	Brilliant lustre. Some fire. Electric by friction or heat
	3.68-3.78	Chrysoberyl	Colorless	1.75	8.5	Bi.(+).009	
	3.94-4.	**Corundum**	.....	1.76-1.77	9	Uni.(—).008	Strong beautiful lustre
		White Sapphire	Colorless	.....	.....	.....	Test 21 for distinction
		Synthetic Sapphire	Colorless				
		Zircon	.....	1.92-1.99	7.5	Uni.(+).062 or .00+	Very brilliant lustre and fire. Opaque to X rays. Internal watery appearance
	4.6-4.7	Matura Diamond	Colorless or faintly yellow				

OPAQUE OR TRANSLUCENT Failing to Give Tests for Single vs. Double Refraction					
2.1-2.2	Opal Hydrophane	..... White or light	1.41-1.45	5.5-6.5	Shows play of colors after immersion in water
2.5-2.6	Serpentine Bowenite	Greenish white	1.52-1.54	5-6	Aggregate polarization Greasy jade-like lustre
2.6-2.65	Chalcedony	Bluish and "tendon" gray	1.52-1.54	6.5-7	Wax like lustre. Fibrous between crossed nicols.
2.9-3.1	Nephrite—(Jade)	Greenish white, grayish, yellowish	1.6-1.63	6.5	Greasy lustre Felted fibres. Opaque to X rays
3.34	Jadeite—(Jade)	Greenish white, reddish white	1.66-1.68	6.5-7	Greasy lustre. No brilliancy
3.3-3.4	Vesuvianite Californite	White	1.69-1.70	6.5	Waxy lustre
Varied	Glass		1.5-1.8	5	

3. Color Violet.

		Specific Gravity	Name	Tint or Shade of Violet	Indices Refraction	Pleochroism	Hardness	Other Distinctions
TRANSPARENT OR VERY TRANSLUCENT.	Singly Refracting.	3.1-3.2	Fluorite		1.43	None	4	Easy cleavage at 70° 31'
			False Amethyst	Bluish				
		3.5-3.7	Spinel		1.73-1.736	None	8.5	Brilliant vitreous lustre. Little fire. Not electric by friction
			Almandine	Violet, lilac, purple				
		3.52	Diamond	Violet	2.417	None	10	Characteristic brilliant lustre and fire
			Garnet					
		3.9-4.2	Almandine	Reddish	1.77-1.81	None	7.5	Characteristic lines in absorption spectra.
		3.79-3.87	Rhodolite	Purplish	1.76	None	7+	
		Varied	Glass		1.5-1.8	None	5	Glassy lustre
	Doubly Refracting.	2.65	Quartz		1.54-1.55		7.	Uni.(+).01 Glassy. In one direction rotates plane polarization
			Amethyst	Violet to purple		Distinct red and bluish		Color poorer in artificial light
		3.16-3.2	Spodumene		1.66-1.67		6.5-7	Bi.(+).026 Very brilliant. Phosphorescent with ultra violet or radium
			Kunzite	Pale to deep lilac		Strong violet, yellowish		Color retained in artificial light
		3.37	Axinite	Violet	1.67-1.68	Strong violet, brown, green	6.5-7	Bi.(—).009 Strong glassy lustre
		3.17-3.23	Apatite	Violet	1.63-1.65	Very faint	5	Uni.(—).004
		3.9-4.1	Corundum		1.74-1.75		9	Uni.(—).008 Strong lustre. Penetrated by X rays
			Oriental Amethyst	Purple or deep violet		Strong		Color improved in artificial light
		4.6-4.7	Zircon	Brownish	1.92-1.99	Very faint	7.5	Uni.(+).062 or .00+ Brilliant lustre and fire. Internal watery appearance

OPAQUE OR TRANSLUCENT Failing to Give Tests for Single vs. Double Refraction							
2.6	Chalcedony	.....	.....	.....	6.5-7	Fibrous between crossed nicols	
	Violette	Pale	.....	.....	.....		
2.8-2.9	Lepidolite	Lilac	1.56-1.60	This test not obtainable except in thin sections or powder of these stones.	2.5-4	Fine pearly scales	
3.2	Pyroxene	.....	1.67-1.73		6		
	Violane	Deep	.....		.....		
3.26-3.36	Dumortierite	Violet	1.68-1.69		7	Usually fibrous	
Varied	Glass	.....	1.5-1.8		5		

4. Color Blue.

TRANSPARENT OR VERY TRANSLUCENT.

	Specific Gravity	Name	Tint or Shade of Blue	Indices Refraction	Pleochroism	Hardness	Other Distinctions	
Singly Refracting.	2.4	Haüynite	Bright	1.49	None	5.5	Not quite transparent	
	3.1-3.2	Fluorite		1.43	.....	4		
		False Sapphire	Dark to nearly black		None		Easy cleavage at 70° 31′	
	3.52	Diamond	Steely or rarely sapphire	2.417	None	10	Characteristic brilliant lustre and fire. Transparent to X rays. Phosphoresces with radium sometimes	
	3.5-3.7	Spinel	.....	1.72	.....	8.5	Brilliant vitreous lustre. Little fire. Not electric by friction	
		Sapphirine	Steely	.....	None			
	Varied	Glass		1.5-1.8	None	5		
Doubly Refracting.	2.6-2.66	Iolite	.....	1.534-1.563	.....	7+	Bi.(—).008	Electric by friction or heat
		Water Sapphire	Clear	.....	Strong			
		Lynx Sapphire	Indigo	.....	Strong blue, light blue and buff			
	2.68-2.75	Beryl	.....	1.57-1.59	.....	7.5+	Uni.(—).006	Brilliant by artificial light
		Aquamarine	Sky	.....	Faint			
		Siberian Aquamarine	Greenish	.....	Faint			
	3.05-3.1	Euclase	Greenish	1.65-1.67	Faint	7.5	Bi.(+).019	Brilliant. Very brittle
	3-3.15	Tourmaline	Quiet colors	1.62-1.65		7+	Uni.(—).02	Strongly electric by heat or friction. Nearly opaque to X rays
		Brazil Sapphire	Light inky	.....	Faint			
		Indicolite	Greenish	.....	Distinct light and dark blue			
	3.17-3.23	Apatite	Greenish and sky	1.64	Very faint	5	Uni.(—).004	
	3.5-3.56	Topaz		1.61-1.64		8	Bi.(+).008	High lustre, some fire, strongly electric by heat or friction
		Brazil Sapphire	Pure pale		Distinct blue and colorless			
	3.56-3.67	Cyanite	Azure to cornflower	1.71-1.78	Distinct light and dark blue	5-7	Bi.(—).016	
					Strong			
	3.64-3.72	Benitoite	Pure to deep with tinge of violet	1.76-1.80	Deep blue and colorless	6-6.5	Uni.(+).047	
	3.9-4.16	Corundum		1.75-1.77	Strong	.....	Uni.(—).008	Strong beautiful lustre. Penetrated by X rays
		Burma Sapphire	Cornflower or dark	.....	Bright and yellowish blue	9		
		Ceylon Sapphire	Light	.....				
		Montana Sapphire	Electric	.....	Australian	.....		
		Australia Sapphire	Greenish	.....	blue and green	.....		See Test 20
		Synthetic Sapphire						
	4.6-4.7	Zircon	Light and dark sky	1.92-1.99	Very faint	7.5	Uni.(+).062 or 00+	Brilliant lustre and fire. Opaque to X rays

OPAQUE OR TRANSLUCENT

Failing to Give Tests for Single vs. Double Refraction

2-2.3	Chrysocolla	Greenish or sky	1.57	.....	2-4	Aggregate polarization. Oftenest cut when mixed with quartz or chalcedony
2.1-2.3	Sodalite	Deep azure indigo or purplish	1.48		5.5-6	Somewhat greasy lustre
2.4	Lapis Lazuli	Deep to purplish	1.49		5.5	Often spotted with pyrite
	Chilian Lapis	Yellowish				With white or gray flecks
2.6-2.65	Chalcedony	.....	1.55	.....	6.5-7	Fibrous between crossed nicols
	Sapphirine	Pale grayish	.....		.....	Appears to contain crocidolite
	Swiss Lapis	Deep (dyed)	.....		.....	
	Blue chrysoprase	Varied	.....		.....	
2.65	Quartz	.....	1.54-1.55		7.	Contains chryocolla malachite and may be green by lamplight
	Sapphire Quartz	Light	.....		.....	Enclosing blue material
	Dumortierite Quartz	Dark	.....		.....	Enclosing blue fibres
	Nunkirk Jasper (German Lapis)	Deep (dyed)	.....		.....	
2.7-2.9	Turquois	Sky to dark or greenish	1.61		6	Color improved in artificial light. Not electric by fricion. Opaque to X rays. Somewhat waxy lustre
	Colored	.....	.....		.....	Grayish blue by artificial light
	Synthetic	Sky to greenish	.....		.....	Cracks and gets deeper blue in water
3-3.5	Odontolite	Sky to dark	.....		5	Made greenish by artificial light
						Organic structure under lens. Electric by friction. More glassy than turquois
3.1	Lazulite	Azure	1.6-1.64	.....	5-6	More glassy than turquois
3.4-3.5	Calamine	Greenish	1.62-1.65	.....	4.5-5	.....
3.8-3.83	Azurite	Dark	1.83-1.85	.....	3.5-4	Essentially color Lapis Lazuli
4.3-4.4	Smithsonite		1.61-1.68	.....	5	.....
	Chalchihuitl	Azure				With lighter bands
Varied	Glass		1.5-1.8	.....	5	.....

This test not obtainable except in thin sections or powder in these stones.

5. Color Green.

TRANSPARENT OR VERY TRANSLUCENT.

	Specific Gravity	Name	Tint or Shade of Green	Indices Refraction	Pleochroism	Hardness	Other Distinctions	
Singly Refracting.	2.36	**Moldavite**	Yellowish	1.51	None	5.5	Full of tiny cavities	
	3.1-3.2	Fluorite		1.43	None	4	Cleavage 70° 31′	
		False Emerald	Emerald					
	3.52	Diamond	Emerald (rare)	2.417	None	10	Characteristic brilliancy and fire. Transparent to X rays. Dispersion .044	
		Garnet						
	3.85	**Demantoid**	Emerald to yellowish	1.88-1.99	None	6-6.5	Great brilliancy and fire in artificial light. Dispersion .057	
	Varied	**Glass**			None	5	Fused fragments emerald	
		Reconstructed Emerald	Emerald		None			
Doubly Refracting.		**Beryl**	.....	.....	.....	.....	Uni.(—).006	Brilliant in artificial light
	2.67	**Emerald**	Like fresh grass in spring	1.57	Strong, bluish green and yellowish green	7.5	.....	Usually cracked or flawed
	2.68-2.75	**Aquamarine**	Bluish	1.57	Faint azure and green	7.5+		
	2.8-3	Prehnite	Oil to dark	1.616-1.649	None	6.-6.5	Bi.(+).032	
	3.05-3.1	**Euclase**	Bluish	1.65-1.67	Faint bluish green and white	7.5	Bi.(+).019	Brilliant lustre
	3.1-3.13	Enstatite	.....	1.66-1.67	Distinct green and yellow	5.5	Bi.(+).009	
		Cape Green Garnet	Yellowish					
	2.94-3.3	**Tourmaline**	Not vivid	1.62-1.68	.....	7+	Uni.(—).02	Strongly electric by heat or friction. Nearly opaque to X rays
		Brazil Emerald	Deep yellowish	.....	Strong, green and blackish			
		Ceylon Peridot	Brownish	.....	Strong yellow and green			
		Ceylon Chrysolite	Yellowish	.....	Distinct			
	3.17-3.19	**Andalusite**	Bottle	1.63-1.64	Strong red, green and yellow	7.5	Bi(—).011	Red reflections from interior
	3.17-3.23	**Spodumene**	.....	1.66-1.67	.....	6.5-7	Bi.(+).026	Very brilliant. More color play than emerald
		Hiddenite	Emerald to yellowish	.....	Strong, bright and dark green			
	3.2	**Apatite**	Bluish to yellowish	1.64	Faint or distinct	5	Uni.(—).004	

TRANSPARENT OR VERY TRANSLUCENT.

Doubly Refracting (continued)

3.2-3.38	**Pyroxene**	.....	1.67-1.76	.....	6	Bi.(+).03	Brilliant
	Diopside	Pale oil to leek or bottle	.....	Faint			
3.3-3.5	**Chrysolite**	Quiet tints	.....	.....	6.5-7	Bi.(+).036	Edges through stones are broad
	Chrysolite	Pale yellowish	1.65-1.69	Faint	.....	.....	More greasy than chrysoberyl
	Peridot	Deep olive to bottle	1.67-1.70	Distinct green and straw	5.5		
3.35-3.45	**Titanite** (sphene)	Yellowish	1.89-2.05	Strong green, yellow, red	6.5	Bi.(+).12	Edges through stone very broad, much fire
3.39-3.45	**Vesuvianite**	Bright leaf	1.70-1.73	Distinct green shades	6.5	Uni.(--).006	Brown and green in different directions
3.47-3.5	**Epidote**	Pistache	1.73-1.77	Strong green, brown, yellow		Bi.(—).037	
3.5-3.56	**Topaz**	Pale bluish	1.61-1.64	Faint	8	Bi.(+).008	High lustre. Some fire. Strongly electric by friction or heat
3.68-3.78	**Chrysoberyl**	.....	1.75-1.76	.....	8.5	Bi.(+).009	Brilliant
3.65	**Alexandrite**	Bluish to dark olive or grass	.....	Strong green orange red	.....	.....	Red in gas or candle light
	Oriental Chrysolite	Pale yellowish	.....	Distinct green yellow			Strong beautiful lustre. Permeable by X rays
3.9-4.1	**Corundum**	.....	1.76-1.77	.....	9	Uni.(—).008	
	Oriental Emerald	Deep	.....	Distinct green and brown			
	Oriental Aquamarine	Light	.....	Faint			
	Oriental Peridot	Yellowish	.....	Faint			
4.3-4.7	**Zircon**	Leaf green also pale or dull	1.92-1.99	None	7.5	Uni.(+).062 or .004	Brilliant lustre and fire. Opaque to X rays

5. Color Green. (Continued)

OPAQUE OR TRANSLUCENT AND Failing to Give Tests for Single vs. Double Refraction

2-2.3	Chrysocolla	Bluish	1.49	.....	2-4	Aggregate polarization. Often mixed with quartz or chalcedony
2.3-2.4	Lintonite	Dull oily	1.5-1.52	.....	5-5.5	
2.55-2.77	**Variscite**	Bright or bluish	1.55	.....	3.5-5	Takes high polish
2.54-2.57	**Microcline**	.....	1.52-1.53	.....	6	
	Amazon Stone	Bluish or verdigris	.....	.....	.....	Usually white spots or streaks
2.5-2.6	Serpentine	Often mottled	1.52-1.54	.....	3-4	Aggregate polarization
	Williamsite	Asparagus				
	Bowenite	Rich oily	.....	.....	5.5-6	Very translucent
2.6-2.65	**Chalcedony**	.....	1.55	.....	6.5-7	Fibrous between crossed nicols
	Chrysoprase	Apple to bluish	.....	.....	.....	Fades on exposure
	Plasma	Dark	.....	.....	.....	Often yellow or white flecks
	Bloodstone	Dark with red spots				
	Emeraudine	Dyed emerald green	1.54-1.55	This test not obtainable except in thin sections or powder in these stones.	.....	
2.65	Quartz	.....	.....		.....	Included actinolite
	Prase	Leek				
	Jasper	Dull gravish				
2.7-2.9	**Turquois**	Bluish, apple or yellowish	1.61		6	More blue in artificial light. Not electric by friction. Opaque to X rays
2.8	Fuchsite	Emerald	1.56-1.60		2.5-3	Minute pearly scales
2.9-3.1	**Nephrite-Jade**	Pale, bright and dark	1.61-1.62		5.5-6	Never brilliant. Lustre greasy. Made of fine felted fibrs
3-3.5	Odontolite	Bluish	.....		5	Organic structure under lens
3.2	Chlorastrolite	Dark mottled			5.5-6	Takes high polish
3.3-3.4	Calamine	Bright to bluish	1.61-1.63		4-5	
3.28	**Vesuvianite**	.....	1.69-1.70		6.5	Aggregate polarization
	Californite	Grass to apple or olive or striped	.....	.....	.....	Waxy to vitreous lustre
3.34	**Jadeite-Jade**	Pale to dark rarely emerald	1.66-1.68	.....	7	Granular to fibrous. Greasy lustre. No brilliancy
3.4-3.6	Chloromelanite	Blackish to spinach	.....	.....	6.5	
3.9-4.03	**Malachite**	Banded light and dark emerald to grass	1.88	.....	3.5-4	
	Smithsonite	.....	1.61-1.81	.....	5	
4.3-4.4	Bonamite	Bluish or apple				
	Glass					
	Paté de Riz	Transulcent whitish to darker	.....	.....	5	Imitation Jade

6. Color Yellow

Transparent or Very Translucent — Singly Refracting.

Specific Gravity	Name	Tint or Shade of Yellow	Indices Refraction	Pleochroism	Hardness	Other Distinctions
1.06-1.08	**Amber**	Saffron or with brown	1.54	None	2-3	Warm to touch, negatively electric by friction. Transparent to X rays
3.1-3.2	Fluorite	.....	1.43	None	4	
	False topaz	Wine yellow				
3.52	**Diamond**	Pale to canary	2.417	None	10	Characteristic brilliancy and fire. Transparent to X rays. Phosphorescent
	Garnet	.....	.....	.....	.....	Great brilliancy by artificial light.
3.6-3.7	Cinnamon Stone	Golden	1.75-1.78	None	7+	Granular under lens.
3.6-3.68	Spinel	Clear to orange	1.72-1.78	None	8	Brilliant vitreous lustre. Little fire
5.4-6.1	Microlite	Pale	Very high	None	5.5	Resinous lustre
Varied	**Glass**	.....	1.5-1.8	.....	5	Glassy lustre

TRANSPARENT OR VERY TRANSLUCENT.

Doubly Refracting.

2.65	**Quartz**	.....	1.54-1.55	.....	7	Uni. (+).01	Glassy lustre. No fire.
	Citrine	Brownish	.....	Faint	.....	.....	In one direction rotates plane polarization
	Cairngorm	Smoky	.....	Faint			
2.68-2.75	**Beryl**	.....	1.57	.....	7.5+	Uni. (—).006	Brilliant lustre
	Golden beryl	Golden	.....	Faint			
	Heliodore	Golden	.....	.....	.....	.....	Green by artificial light
	Aquamarine Chrysolite	Greenish	.....	Faint			
2.94-3.3	**Tourmaline**	Not vivid	1.62-1.68	.....	7+	Uni. (—).02	Electric by heat and friction. Nearly opaque to X rays
	Ceylon chrysolite	Greenish	.....	Distinct			
2.96	**Danburite**	Wine	1.635	.....	7+	Bi (—).004	
3.2	**Spodumene**	Pale or lemon	1.66-1.67	Faint	6.5-7	Bi. (+).026	Brilliant
3.17-3.23	**Apatite**	Brownish	1.64	Faint or distinct	5	Uni. (—).004	
3.3-3.5	**Chrysolite**	Greenish	1.65-1.69	Faint	6.5-7	Bi. (+).036	Edges broad through stone
3.35-3.45	**Titanite**	Greenish or brownish	1.89-2.05	Strong	5.5	Bi (+).12	Adamantine lustre. Edges very broad through stone
3.5-3.56	**Topaz**	.....	1.63-1.64	....	8	Bi. (+).008	High lustre. Strongly electric by heat or friction
	Brazil topaz	Golden to brownish	.....	Distinct			
	Saxon topaz	Pale	.....	Faint			
3.68-3.78	**Chrysoberyl**	.....	1.75-1.756	.....	8.5	Bi. (+).009	Brilliant. Stronger pleochroism than corundum.
	Oriental chrysolite	Greenish or brownish	.....	Distinct yellow green			
3.9-4.1	**Corundum**	.....	1.76-1.77	.....	9	Uni. (—).008	Strong beautiful lustre. Penetrated by X rays.
	Oriental topaz	Golden	.....	Distinct			
			1.69-1.71	yellow shades			
	Oriental chrysolite	Greenish	.....	Faint			
	Synthetic Sapphire	Golden	.....	Distinct	.....	.....	See Test 20
3.9-4.2	**Willemite**	Golden or greenish	1.69-1.71	.....	5.5	Uni. (+).019	Phosphoresces with ultra violet
4.3-4.6	**Zircon**	.....	1.92-1.99	.....	7.5	Uni. (+).062 or .00+	Great brilliancy and fire. Opaque to X rays
	Jacinth	Golden or rich orange	.....	Very faint			
6-8-7.1	**Cassiterite**	Brownish	2-2.09	Faint	6.5	Uni. (+).097	Very brilliant

6. Color Yellow. (Continued)

OPAQUE OR TRANSLUCENT — Failing to Give Tests for Single vs. Double Refraction

Specific Gravity	Name	Tint or Shade of Yellow	Indices Refraction	Pleochroism	Hardness	Other Distinctions
2.2	Natrolite	Straw	.....	This test not obtainable except in thin sections or powder in these stones.	5-5.5	Concentric bands to radiating fibres
2.4-2.5	Cancrinite	Orange to brownish	1.49-1.52		5-5.6	Lustre somewhat greasy
2.5-2.65	Serpentine	Straw or sulphur or mottled	1.52-1.54		2.5.-4	Aggregate polarization
2.65	Quartz	.....	1.54-1.55		7	
	Jasper	Ochre	.....		.....	Opaque
2.6-2.65	Chalcedony	Pale (dyed), reddish	1.52-1.54		6.5-7	Translucent. Fibrous between crossed nicols
4.3-4.4	Smithsonite	Cadmium	1.61-1.81		5	
4.9-5.2	Pyrite	Brass	.....		6-6.5	Metallic lustre
Varied	Glass	.....	1.5-1.8		5	Glassy lustre

7. Color Brown.

TRANSPARENT OR VERY TRANSLUCENT.

	Specific Gravity	Name	Tint or Shade of Brown	Indices Refraction	Pleochroism	Hardness	Other Distinctions
Singly Refracting.	1.06-1.08	**Amber**	Yellowish or with yellow	1.54	None	2-3	Warm to touch. Negatively electric by friction. Transparent to X rays.
	3.1-3.2	Fluorite	Dark	1.43	None	4	Easy cleavage at 70° 31′
	3.52	**Diamond**	Pale to rich	2.417	None	10	Characteristic brilliancy and fire. Transparent to X rays. Phosphorescent
	3.6-3.68	Spinel	Faun to reddish	1.72-1.73	None	8	Brilliant vitreous lustre. Little fire
		Garnet			None		Greater brilliancy by artificial light
	3.6-3.7	**Essonite**	Reddish to orange	1.75-1.78		7+	Granular under lens
	3.7-3.8	**Vermeille**	Reddish	1.79-1.81		7+	Not a clear color
	4-4.3	**Spessartite**	Reddish	1.79-1.81		7.5-8	More brilliant than essonite
	Varied	**Glass**		1.5-1.8		5	Glassy lustre
Doubly Refracting.	2.65	**Quartz**		1.54-1.55		7	Bi.(+).01 Glassy without fire. In one direction rotates plane polarization
		Smoky Quartz	Smoky		Faint		
		Madeira Topaz	Fiery dark		Distinct		
	3.1-3.2	Chondrodite	Reddish	1.61-1.64	Distinct browns	6.5	Bi(+).032
	2.94-3.3	**Tourmaline**	Rich	1.62-1.68	Strong brown nearly black	7+	Uni.(—).02 Strongly electric by heat or friction Nearly opaque to X rays
	3.17-3.19	**Andalusite**	Reddish	1.63-1.64	Strong, brown, green, yellow	7.5	Bi.(—).011 Pleochroic in all directions
	3.27	**Axinite**	Clove to smoky	1.67-1.68	Strong, violet, brown green	6.5-7	Bi.(—).009 Strong glassy lustre
	3.35-3.45	**Titanite**	Yellowish	1.89-2.05	Strong	5.5	Bi(+).12 Adamantine lustre. Edges through stone very broad
	3.39-3.43	Vesuvianite	Yellowish	1.70-1.73	Distinct	6.5	Uni.(—).006
	3.5-3.56	**Topaz**	Yellowish	1.63-1.64	Distinct	8	Bi.(+).008 High lustre. Strongly electric by heat or friction
	3.65-3.75	Staurolite	Reddish	1.74-1.75	Faint	7.5	Bi.(+).01
	4.6-4.7	Zircon	Reddish	1.92-1.99	Faint	7.5	Uni.(+).062 Great brilliancy and fire 00+ Opaque to X rays

OPAQUE OR TRANSLUCENT

Failing to Give Tests for Single vs. Double Refraction

2.5-2.6	Obsidian	Mahogany	.....	This test not obtainable except in thin sections or powder in these stones.	5.5	Breaks like glass
2.6-2.65	Chalcedony	.....	1.53-1.54		6.5-7	Fibrous between crossed nicols
	Sard	Reddish				
2.65	Quartz	.....	1.54-1.55		7	
	Jasper	Chestnut	.....		.....	Often banded
Varied	Glass	.....	1.5-1.8		5	Glassy lustre

TRANSPARENT OR VERY TRANSLUCENT.

Singly Refracting.

8. Color Red.

Specific Gravity	Name	Tint or Shade of Red	Indices Refaction	Pleochoism	Hardness	Other Distinctions
1.06-1.08	Amber	Brownish	1.54	None	2.5	Warm to touch, negatively electric by friction
3.1-3.2	Fluorite	.....	1.43			
	False Ruby	Rose	.....	None	4	Cleavage at 70° 31
3.52	Diamond	Pink to ruby	2.417	None	10	Characteristic lustre and fire. Transparent to X rays. Phosphoresces with radium
3.6-3.63	Spinel	.....	1.72-1.73	None	8	Colors clearer than garnet
	Balas ruby	Rose pink	.....	.....	.....	Yellow tint from depth of stone in all red varities Brilliant lustre, but little fire
	Ruby spinel	Lively red				
	Rubicelle	Orange				
	Almandine	Violet				
	Garnet					
3.6-3.7	Essonite	Golden	1.75-1.78	.....	7+	Granular "sugar candy" effect
3.7-3.8	Pyrope	Blood to blackish or ruby	1.74-1.81	.....	7+	Not a clear color. Often a tinge of yellow
3.7-3.8	Vermeille	Brownish	1.79-1.81	.....	7+	
3.84	Rhodolite	Rose pink	1.76	.....	7+	Lines in absorption spectrum
3.9-4.2	Almandine	Brownish or crimson	1.77-1.81	.....	7.5	Lines in absorption spectrum
4-4.3	Spessartite	Aurora	1.79-1.81	.....	7.5-8	More brilliant than essonite

TRANSPARENT OR VERY TRANSLUCENT								
Doubly Refracting.								
	2.79	**Beryl**	.....	1.59-1.60	....	7.5	Uni. (—).006	Brilliant lustre. Cerise under X rays
		Morganite	Rose to salmon	.....	Faint or none			
	3.2	**Spodumene**	.....	1.66-1.67	Strong	6.5-7	Bi.(+).026	Brilliant. Phosphorescent with ultra violet, X ray or radium
		Kunzite	Pink with tinge lilac Not vivid	.....	violet and yellow			
	3-3.16	**Tourmaline**	....	1.61-1.64	.....	7+	Uni. (—).02	Strongly electric by heat or friction. Nearly opaque to X rays
		Rubellite	Rose to pink	.....	Strong			
		Siberian ruby	Dark	.....	Rose and dark red			
		Siberite	Violet					
		Apyrite	Cherry					
	3.22-3.26	**Piedmontite**	Cherry	.....	.....	6.5	Bi.(—).05	
	3.5-3.56	**Topaz**	.....	1.76-1.77	Strong	8	Bi.(+).008	High lustre
		Brazil ruby	Pink, rose	.....	Distinct, yellow and red			
	3.93-4.01	**Corundum**	.....	.....	.....	9	Uni.(—).008	Strong beautiful lustre. Penetrated by X rays. For comparison see Test 21
		Ruby natural or synthetic	Rose, blood red Carmine	.....	Distinct, red and purplish			
	4.65-4.8	**Zircon**	Sombre deep	1.92-1.96	Faint	7.5	Uni. (+).062	Great brilliancy and fire Opaque to X rays
OPAQUE OR TRANSLUCENT								
Failing to Give Tests for Single vs. Double Refraction								
	2.65	**Quartz**	.....	1.54-1.55	This test not obtainable except in thin sections or powder in these stones.	7	.....	Bleached by sunlight
		Rose Quartz	Pink	.....				
		Jasper	Dark or mottled					
	2.6-2.65	**Chalcedony**	.....	1.52-1.54		6.5-7		Fibrous between crossed nicols
		Carnelian	Bright					
		Sard	Brownish					
	2.67-2.68	**Coral**	Rose Pink to Bright or flesh	1.48		3.5-4		Organic structure (hollow cones fitted within each other
	2.8-2.9	**Lepidolite**	Pink to cherry	1.56-1.60		2.5-4		Minute scales
	3.2-3.35	**Zoisite**	.....	1.70		6-6.5		
		Thulite	Rose to peach					
	3.4-3.7	**Rhodonite**	Rose pink to flesh, often with black	1.72-1.74		5.5-6.5		Very tough
	4.2-4.3	**Rutile**	Blackish	2.6-2.9		6-6.5		Very high lustre
		Glass				5		No organic structure
		Bone Horn Ivory	Imitation of Coral	1.5-1 8	.....	.....		
		Celluloid, etc.						

9. Color Black or nearly.

Specific Gravity	Name	Shade of Black	Hardness	Indices Refraction	Other Distinctions
1.35	Jet	Deepest	3-4	.....	Warm to touch. Brilliant greasy lustre.
2.5-2.6	Obsidian	Velvety or smoky	5.5	1.50	Transparent to X rays Singly refracting. Breaks like glass
2.6-2.65	Chalcedony (dyed)	Deep	6.5-7	1.55	
2 65	Quartz	.....	.....	1.54-1.55	
	Morion	Velvety	7		
3 2	Tourmaline	Pure or bluish	7+	1.62-1.68	Electric by friction or heat
3.3-3.4	Allanite	Pure	5.5-6	1.68-1.70	
3.52	Diamond	.....	10	2.417	Great brilliancy. Transparent to X rays
	Spinel	.....	8	1.78	
3.57	Cevlonite	Greenish	.....	.....	
4.2-4.3	Rutile	Reddish	6-6.5	2.6-2.9	Cut as imitation black diamond. Opaque to X rays. Strongly pleochroic
4.1-4.4	Gadolinite	Velvety	6.5-7	>1.78	
4.5-5	Ilmenite	Brilliant	5-6	.....	
4.9-5.2	Magnetite (Lodestone)	.....	5.5-6.5	.....	Magnetic. Brilliant lustre
5.3	Hematite	Brilliant	5.5-6.5	2.79-3	Red streak. Cut to imitate black pearls
5.6-5.8	Samarskite	Velvety	5-6	.....	Submetallic
	Glass				

Cut Stones Showing more than one Color.

Deposition of one material in layers of different color, inclusions of foreign material, the close assoc ation of two or more different materials, and other causes have led to the cutting of stones in v.hich two colors are visible. For the most part these have been described under the dominant color. A few not easily so described are:

Thomsonite.—Parallel layers, flesh red, white, green; etc.
Chalcedony.—
Agate.—Varied colors in bands, clouds, etc.
Moss Agate.—Interlaced green or brown moss-like inclusions in chalcedony.
Mocha Stone.—Tree like (dendritie) material often black in chalcedony.
Onyx.—Parallel layers black and white or black brown and white.
Sardonyx.—Parallel layers red and white or red and black.

Andalusite.—
Chiastolite.—White geometric figures on darker background.
Azur Malachite.—Layers Azurite and Malachite.
Prase Malachite.—Malachite in green chalcedony.
Amatrix.—Apple and emerald green variscite with chalcedony.
Turquois Matrix.—Turquois with brown flecks and bands.
Ruby Matrix.—Ruby grains in grass-green smaragdite.
Opal Matrix.—Brown Jasper or other matrix with the opal.

10. Supplementary Tables.

To be used either when fragment is available or when the test can be made on the back of the stone.

Name	See Tables	Effect of Heat		Effect of Acids		Other Tests
		Closed Tube Low Red	Forceps and Blowpipe	Concentrated Hydrochloric	Dilute Hydrofluoric	
Allanite	9	Gives water	Fuses 2.5 bubbles	Jelly	Etched	Becomes magnetic on fusion
Amber	6, 7, 8	Melts 250°C Aromatic odor	Chars and volatalizes	Insol.	Insol.	Not sticky with alcohol
Andalusite	5, 7	.....	Infus	Insol.	Insol.	Poor cleavage near 90°
Apatite	3, 4, 5, 6	Loses color	Fuses (6) whitens	Sol.	Etched	Test for phosphorus
Axinite	3, 7	Violet to brown to colorless	Fuses easily	Insol.	Insol.	Green flame of boron
Azurite	4	Blackens	Fuses (3) green flame	Effervesces leaves crystals	.....	Globule of copper by fusion
Benitoite	4	Unchanged	Fuses (3) transparent	Insol.	Etched	S.Ph and R.F. violet
Beryl	2, 4, 5, 6, 8	.....	Fuse (5-6)	Insol.	Insol.	
Emerald		Unchanged	....	.....	.....	S.Ph and R.F. green
Aquamarine		Loses color	.....	.....	.....	.....
Morganite		Whitens	.....	.....	.....	.....
Beryllonite	2	.....	Fuses (3) yellow flame	Etched	Insol.	Decrepitates
Calamine	4, 5	Whitens	Fuses (6)	Jelly	Insol.	Decrepitates. Sublimate on charcoal
Calcite	1	Unchanged	Infus. Glows	Effervesces	.....	Colors flame red
Cancrinite	6		Fuses white	Effervesces	.....	Yellow flame
Cassiterite	6	Unchanged	Infus. Glows	Insol.	.....	Sublimate on charcoal
Chlorastrolite	5	Browns	Fuses	Etched	.....	.....
Chondrodite	7	Blackens	Infus.	Jelly	Etched	
Chloromelanite	5	.....	Fuses (2.5)	.....	.....	Yellow flame
Chalcedony	2, 3, 4, 5, 6, 7, 8, 9	Usually whitens, becomes opaque	Infus.	Insol.	Etched	
Chrysoberyl	1, 2, 5, 6	.....	Infus.	Insol.	Insol.	
Chrysolite	5, 6	Changes color	Infus. whitens	Jelly	Etched	Green copper flame
Chrysocolla	4, 5	Blackens yields water	Infus.	Green solution	Etched	
Coral	8	Blackens	Infus.	Effervesces	.....	When heated opens out into concentric layers

Name	See Tables	Effect of Heat		Effect of Acids		Other Tests
		Closed Tube Low Red	Forceps and Blowpipe	Concentrated Hydrochloric	Dilute Hydrofluoric	
Corundum	1, 2, 3, 4,5, 6, 8	Lessens color	Infus.	Insol.	Insol.	Sometimes breaks at 86° 4′
Ruby	.....	Whitens, cools green, then red.	.....	.....	.....	
Sapphire	.....	Turns yellow rose	.....	.....	.....	
Or. Amethyst	.....					
Cyanite	1, 4	Loses color	Infus.	Insol.	Insol.	Easy cleavages
Datolite	2	Water	Fuses transparent	Jelly	.....	Green flame of boron
Danburite	2, 6	Red phosphorescence	Infus.	Insol.	Insol.	Green flame of boron
Diamond	2, 4, 5, 6, 7, 8	Unchanged	Infus. Slowly burned	Insol.	Insol.	Cleavages 70° 31
Dumortierite	3	Violet darkens, blue is lighter	Infus.	Insol.	.....	Green flame of Boron
Elaeolite	1	.....	Fuses	Jelly	.....	Yellow flame
Enstatite	5	Blackens	Fuses diff.	Insol.	Insol.	
Epidote	5	Water at red heat	Fuses easily dark	Insol.	Insol.	
Euclase	4, 5	Whitens, yields water	Fuses diff. (6)	Insol.		
Fluorite	3, 4, 5, 6, 7, 8	Phosphoresces	Fuses red flame	Drilled	Insol.	Easy cleavages at 70° 31′
Fuchsite	5	.....	Infus.	Insol.	....	S.Ph. R.F. green
Gadolinite	4	Unchanged	Fuses (5-6)	Jelly		
Garnet	3, 5, 6, 7, 8	Often unchanged	Fuses, dark	Insol.	Insol.	
Pyrope	.....	Darkens, regains color	.....	.....	.....	
Demantoid	.....	Browns	.....	.....	.....	
Glass	1, 2, 3, 4, 5, 6, 7, 8, 9	.....	Fuses	Insol.	Etched	
Gypsum	1	Whitens	Fuses	Sol. crystals	.....	Red flame
Haüynite	4	.....	Fuses white	Jelly and odor	.....	
Hematite	9	Unchanged	Infus., becomes magnetic	Tarnished	Insol.	Reddish brown powder
Hypersthene	1	Unchanged	Fuses (5)	Insol.	.....	Fused mass is magnetic
Ilmenite	9	Unchanged	Infus.	Etched	Insol.	Dark brown powder
Iolite	4	Whitens	Fuses diff.	Etched	Insol.	
Jadeite	2, 5	Unchanged	Fuses (2.5)	.....	Insol.	Strong yellow flame
Jet	9	Yellow liquid evolved	Burns	Insol.	.....	Smoky flame
Labradorite	1	Unchanged	Fused (3.5)	Insol.	Etched	Easy cleavages at 86°
Lazulite	4	Whitens	Infus. Falls to pieces	Insol.	Etched	Blue flame of Phosphorous
Lapis Lazuli	4	Darkens, Glows green Darkens	Fuses (3.5)	Jelly		Fine powder shows blue inclusions

Name	See Tables	Effect of Heat		Effect of Acids		Other Tests
		Closed Tube Low Red	Forceps and Blowpipe	Concentrated Hydrochloric	Dilute Hydrofluoric	
Lepidolite	3, 8	Fades	Fuses	Insol.	Insol.	Purplish red flame Litheum
Lintonite	5	Fades, yields water	Fuses (2.5)	Sol. Jelly	.....	Lithum
Malachite	5	Blackens, yields water	Fuses black	Effervesces	.....	Green flame copper
Microline						
Amazonite	5	Whitens	Fuses (5)	Insol.	Etched	Cleavages approx. 90°
Microlite	6	.....	Infus.	Insol.		
Moldavite	5	.....	Fuses	Insol.	Etched	Glassy fracture
Moonstone	1	Unchanged	Fuses (3.5)	Insol.	Etched	Cleavages near 90°
Natrolite	6	.....	Fuses, transparent	Jelly	.....	Yellow flame
Nephrite (Jade)	2, 5	Unchanged	Fuses (4)	Etched	Insol.	Very little flame
Obsidian	1, 9	Unchanged	Fuses	Insol.	Etched	Glassy fracture
Odontolite	4, 5	.....	Unpleasant odor	.....	Effervesces	
Opal	1	Loses play of color, becomes opaque	Infus.	Insol.	Etched deeply	Water in closed tube
Pearl	1	.....	.....	Effervesces		Red flame
Phenacite	2	.....	Infus.	Insol.	Etched	
Piedmontite	8	.....	Fuses (3) black	Insol.	.....	Borax O.F. amethystine
Prehnite	5	Retains color	Fuses (2.5) white	Etched	Etched	
Pyroxene	5	Color changed or lost	Fuses colored	Insol.	Insol.	Cleavages 87° 10′
Diopside						
Pyrite	6	Gives off S	Fuses, black magnetic	Insol.	.....	Burns blue flame
Quartz	1, 2, 3, 4, 5, 6, 7, 8, 9	.....	Infus.	Insol.	Insol.	Glassy fracture
Amethyst		Yellows				
Citrine		Whitens				
Rose		Whitens				
Smoky		Whitens				
Rhodonite	8	Darkens	Fuses (3) black	Insol.	Etched	Borax O.F. amethystine
Rutile	8, 9	Unchanged	Infus.	Insol.	Insol.	S.Ph. R.F. violet
Samarskite	9	Glows, cracks	Fuses (4.5-5)	Insol.	Insol.	Sublimate on charcoal
Serpentine	1, 2, 5, 6	Darkens	Fuses (5) black	Etched	Etched	
Smithsonite	4, 5, 6	Darkens	Infus. Glows	Effervesces	.....	Sublimate on charcoal

Name	See Tables	Effect of Heat		Effect of Acids		Other Tests
		Closed Tube Low Red	Forceps and Blow-pipe	Concentrated Hydrochloric	Dilute Hydrofluoric	
Sodalite	4	Whitens	Fuses (4) colorless	Loses color Jelly forms	Etched	White powder yellow flame
Spinel	2,3,4,5,6,7,8,9	Loses and regains color	Infus.	Insol.	Insol.	Cleavages 70° 31
Spodumene	2, 3, 5, 6, 8	.....	Fuses easily	Insol.	Insol.	Purplish red flame of lithia
Staurolite	7	.....	Infus.	Insol.		
Sunstone	1	Unchanged	Fuses (3.5)	Insol.	Etched	Cleavages at 86°
Thomsonite	9	Whitens, breaks up	Fuses easiy	Jelly	.....	
Titanite	5, 6, 7	Changes color	Fuses (3) black	Insol.	Etched	S.Ph. R.F. violet
Topaz	2, 4, 5, 6, 7, 8	Brazil yellow turns pink. Ceylon whitens	Infus.	Insol.		
					Insol.	One easy cleavage
Tourmaline	2, 4, 5, 6, 7, 9	Varies	Fuse Diff.	Insol.		
					Insol.	Green flame of boron
Turquois (Natural)	4, 5	Browns, splits up	Infus.	Sol.	.....	Greenish flame of copper
Synthetic	.....	.....	Fuses, black	Sol.	.....	Cracks in water, becomes more blue
Variscite	5	Reddens, yields water	Infus.	Insol.	Etched	
Vesuvianite	5, 7	.....	.....	Insol.	Insol.	
Californite		Loses color regains	Fuses. Dark			
Willemite	6		Fuses diff.	Jelly		Sublimate on charcoal
Zircon	2, 3, 4, 5, 6, 7,8	Loses color	Infus.	Insol.	Insol.	
Zoisite	8					
Thulite	.....	Darkens regains color	Fuses (3.5) white	Insol.	Insol.	

DESIGN OF SURFACE COMBUSTION APPLIANCES*—II

BY CHARLES E. LUCKE.

3. Control and Adjustment of Radiating Surface.

By the application of the principles of construction so far developed, it is possible to make a surface combustion burner for any desired rate of combustion per square foot of hearth, which will operate for indefinite periods of time without disturbance or adjustment, but for commercial apparatus more than this is needed. One additional feature that must be present is a suitable range of control of the rate, since few burners are actually operated at a constant rate of combustion whether used for domestic or industrial purposes. It must be possible, therefore, to adjust the consumption of the burner from a minimum to a maximum rate, and to operate safely and surely at any one, no matter what the previous adjustment or the time of operation. Furthermore, some classes of service require a very prompt change in the radiating bed temperature after adjustment, which includes a very quick initial heating after lighting cold, while other classes of service require a slow change after adjustment or a sluggish response to changes. With any given range of adjustment of rates for safe working may be associated the requirement of a prompt or a sluggish response after a change; but fortunately in no one burner is it ever necessary, or even desirable, to provide for more than a limited range of adjustment, associated with either prompt heating or sluggish, never both. These conditions can be met in the sort of burners described sufficiently well to meet practically all service requirements consistent with maintaing the advantages of surface combustion as a process.

The control of combustion rate depends primarily on the size of feed holes and on the effectiveness of their cooling, and it is easily possible to make holes small enough, in separate tubes or ribs, absolutely to prevent back-flash even when the

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mixture is turned off and the velocity of the flow reduced to zero. By imposing sufficient pressure on enough of these holes per square inch of hearth any maximum rate of combustion may easily be associated with this minimum rate of zero. Certain practical considerations, such as the extra cost of forming small rather than large feed holes, and the increased possibilities of stoppages in them, make it desirable to use larger holes than correspond to a minimum rate of zero, when that is not necessary, and it has been found that holes of 1/16 in. diameter are small enough for safe operation at rates as low as most services require. Holes of this size in cook-stove burners, broilers, and room heaters, can be safely operated at 0.2 or 0.3 in. pressure, giving thereby at least as great a range of adjustment as is possible with bunsen burners of the ordinary form, without back flash. Such holes seem to keep free of stoppages and are cheap to form, if not much over 1 in. long. Apparatus intended normally for much higher rates than the domestic class would naturally be given larger holes and, therefore, have a higher minimum operating pressure, but the range desired even with this higher minimum is easily obtained by using a correspondingly higher maximum. Thus, while the maximum pressure available for operating domestic apparatus without gas boosting, which is out of the question here, is a little less than that of the street main, say 3 in. of water, that for an industrial furnace, for which gas boosting is not objectionable, may be made as high as 12 in. with small fans and with positive blowers several pounds. Assuming the holes in the latter case to be such that the minimum safe pressure is 1 in., there is a pressure range of 12:1 for adjustment of rate. Correspondingly, if the domestic apparatus has a minimum safe pressure of 0.2 in., then it has an adjusting pressure of 15:1. It must not be understood that these are limiting figures, for they are not, being offered merely as examples; the real range may be made whatever is desired, a thing thought to be impossible in the early days of surface combustion development.

The time of heating is likewise within control, though not through so wide a range, that is, by adopting suitable constructions the burner may be made to heat up from the initial cold to the normal working state in a short or a long time,

and will be correspondingly quick or sluggish in response to pressure or rate adjustments while in operation. Sluggishness is obtained by using a thick bed of great mass and, therefore, of large heat storage capacity, while sensitiveness follows the use of beds or radiating surfaces as light as possible. It is clear that, taking for example the cook-stove top burner, a bed only ¼ in. thick will heat quicker and respond more positively to valve adjustments than a bed 1 in. thick, other things being equal, and the time of heating the latter would approximate four times that of the former if there were no interfering influences. These influences are present, however, and are somewhat difficult to understand at first, but clear enough after study.

In the first place, a reduction in the thickness of bed may leave it so thin that it is no longer effective in reducing mixture velocity at the hearth orifices, so that mixtures will blow off at various points where the grain does not properly baffle a jet. The escape of this mixture actually reduces the heat developed in the bed, delays its heating, and so counteracts the expected gain from reduction of bed mass; at the same time it causes a smell from the escape of the unburned gas, which, of course, ceases once the bed is heated, even when the baffling is very poor. This is one of the difficulties encountered in the effort to reduce initial heating time by diminishing the thickness of bed. It would seem that, if starting with grain ¼ in. diameter, a reduction of bed thickness was carried so far as to cause partial blow-off by insufficient baffling, this could be corrected by a reduction in size of grain, and this is so, but here again limits are met. In no case may the grain be so small as to fall into the end of the tube, but with the small holes used, even before this occurs two things are noted. A thin layer of fine grains on a flat hearth will not heat uniformly, with the hole spacing satisfactory for larger grains, a series of bright spots above each hole will replace the uniform color of a thicker and, therefore, more sluggish bed. Again, the fine-grain bed will not heat initially in the same way that the coarse one will, for below a certain size of grain the combustion locates initially on the outside surface, which heats first, the combustion zone gradually working back toward the orifices, while with a larger grain, offering fewer and wider passages in the voids, the combustion zone locates instantly

about the holes, flashing directly through the bed. In other words, the fine-grain bed heats from the surface inward, while the coarse heats from the inside outward; and though for two such beds of equal weights of material it would seem that equal times must elapse before each reaches a steady state, as a matter of fact the one that heats first from the outside will be quicker because of the non-escape of unburned mixture while heating.

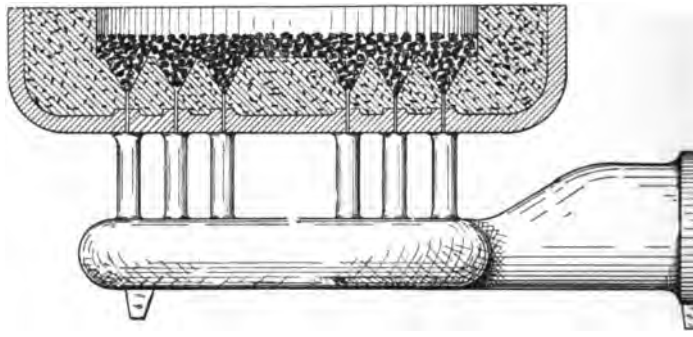

Fig. 18. Modification of tubular type cook stove burner for quick initial heating.

The reasoning leads naturally to one of the successful forms of quick-heating top burners, which becomes incandescent and uniform, at the normal rate of combustion, in about half a minute, the ordinary ½-in. thickness of large-grain bed requiring 2 to 4 min., depending on the material. This one is formed by counter-sinking the outlet side of the 1/16-in. feed holes to ½ in., filling the taper holes with silica of size 5/32 to ⅛ in., and almost covering the hearth to a depth of ¼ in., as indicated in Fig. 18.

Reduction of mass to be heated, without intereference with the effectiveness of the baffles, and by using materials that are permanent, is a definite problem for which there are many solutions, and no doubt others will appear as long as specific attention is given to it; but it is a serious question whether reduction of time below 1 min., or even to this time, is really advisable. One available type of construction, already explained under localization, is the formed baffle, of which the flat-plate mushroom plug, and ball in taper hole are examples; over these may be placed a radiant screen of metal, perforated or

woven, a thin layer of loose grain, or a diaphragm of refractory, perforated or otherwise formed porous enough to allow the free passage of gases; all of these have been tried, as well as some others that proved unsatisfactory. In the latter class may be mentioned a layer of picked asbestos fiber, which heats as quickly as an illuminating mantle, but has no life; a ¼-in. layer of hollow cylinders or short thin silica tubes like straight beads, ⅛ to ¼ in. diameter and ⅜ in. long, which heats in less than 1 min. and is permanent but too expensive; and a thin plate of alundum cement perforated freely with ⅛-in. holes, which becomes incandescent in 1 min. but is too fragile. In the former class are the perforated non-oxidizing metal plate over some form of direct baffle; and the molded porous diaphragm directly over the holes, serving as both baffle and radiator; the former affords a very quick heating but is not so permanent as the latter, which heats more slowly. For metal plates two materials have been used, Nichrome II and Excello, the analyses of which are given below, as determined by Whitaker and Metzgar.

Composition of Non-Oxidizing Alloys.

Nichrome			Excello	
Sample No. 1	Per cent.	Sample No. 2 Per cent.		Per cent.
Nickel	56.4	59.9	Nickel.....	83.43
Chromium	10.6	10.8	Chromium.....	14.72
Iron	30.6	26.2	Iron.....	1.30
Manganese	2.1	2.3	Silica.....	Trace
	99.7	99.2		99.45

The former has been used, and, as applied to the problem of quick heating, was in sheet form, 0.032 in. thick, perforated with holes 0.073 in. diameter, and about one diameter apart. This was cut circular to fit the top burner hearth 4⅜ in diameter, and heats to normal in about ½ min. when set over baffles of the mushroom or plate type, and in about 10 sec. with ball baffles. Such plates have a fair life if not operated at too high a temperature, about 1 cu. ft. of gas per hr. for each 2 in. of radiation is a satisfactory rate and gives a good red heat. This construction may, therefore, be adopted as a direct competitor of the electric heater, using the same radiant material at the same temperature, but with gas as the source of heat instead of electric current.

It is a serious question whether the reduction of heating time should be carried so far, even in domestic apparatus,

in spite of a demand for it, because of the corresponding small heat storage. A top burner carrying ½ in. loose bed has so much heat storage that it will resist interference from the spilling on it of large quantities of water or grease in amounts sufficient to be serious with bunsen burners, but the more this heat storage is reduced by constructing for quick heating, the less the resistance. Another advantage of heat storage in the incandescent bed is inherent to all intermittent heating, such as the heating of laundry irons, which may thereby absorb heat for a time faster than it is being generated, by drawing on the bed storage. Irons always heat faster on the surface combustion burner than on a common burner of equal gas consumption; one trial burner showed that with two irons on a surface combustion burner a laundress could do as much work as with three irons on the bunsen, the former consuming about half the gas that the latter used, and heating the iron in less time.

The application of the bonded diaphragm to general service conditions is a problem in itself, as the localization of combustion is not so readily controlled under wide ranges of mixture pressures within the limits imposed by the ordinary domestic gas service. All such diaphragms, except those of very great porosity and, therefore, necessarily thick, will heat from the outside inward, the combustion zone following until back-flash takes place. Assuming that general service apparatus will be operated at a variable rate and hence variable pressures, then the localization of combustion by diaphragms is not to be depended upon, but they are still useful as baffles and radiators when placed over a hearth, such as described, the latter insuring localization. A bonded diaphragm placed over such a hearth as, for example, that of the cook-stove top burner, will, on ignition, heat from the outside first; the combustion zone will then work down and through it until a back-flash occurs and the combustion zone locates between the hearth and the bottom face of the diaphragm, extending from each hole a little way into the diaphragm if it lies directly on the hearth. As the heat works back unevenly, due to inequality of voids and size of grain, at instant of back-flash there will be only one hot spot, all the rest of the bottom and the hearth being cold. Up to this moment the outer surface has been hot and radiating, but now the heat will be prac-

tically all absorbed by the hearth and lower space until they become incandescent; during this period the top radiating surface will first cool and then slowly recover its temperature, after which it will operate indefinitely without change. The time it takes for the outer surface to begin to radiate, and for the back-flash to occur, are both dependent on the relation of porosity to pressure or rate of supply, but the time of recovery after the back-flash is largely controlled by uniformity of diaphragm. If the combustion zone works back equally fast all over the diaphragm, the bottom face will be hot all over when bottom ignition takes place, instead of at only one spot, and hence the top temperature will be recovered most rapidly.

A great many small diaphragms of all kinds of materials and bonds have been tried, and all abandoned in favor of alundum, which has been prepared by the Norton company, to whom considerable credit is due for the spirit of co-operation displayed in opening up a new field absolutely without data. Without reciting the details, it may be noted that satisfactory results are obtained with Norton alundum diaphragms fed through the self-cooling mixture holes, and set over the discharge hearths. These are structurally quite strong if the bond used is not intended for very high temperatures, in which case they are delicate but still useful for some purposes. The time of back flash and recovery of surface temperature varies considerably, but in the best diaphragms the whole time is about 5 min., in some cases reaching 15 and even 20 min. The time of recovery varies from 3 to 12 min., the better diaphragms requiring the lesser time, all at pressures of 1½ in. of water.

4. Auxiliary Apparatus.

Any burner or furnace intended for laboratory use, where operators have sufficient skill and understanding of cause and effect, need not be supplied with any special appliances for proportioning air to gas in the mixture, or for changing the mixture pressure as service conditions require it; therefore, any of the many standard fans and blowers may be used for compressing air alone or air and gas separately, with a hand adjusted cock in the air and the gas pipes supplying each appliance. This is by no means the case, however, with some industrial and with all domestic appliances. Where an in-

dustrial furnace operator is more or less constantly engaged in managing one furnace, he can be taught to make adjustments of hand valves if provided with the ordinary water column water gauge and a small sampler burner, but this is entirely out of the question for the ordinary woman in the home or chef in a hotel, as these either cannot or will not adjust anything beyond turning the cock that regulates the heat, and sometimes not even this. For domestic service, including that of hotels and restaurants, it may reasonably be expected that they operate a single cock for each burner to regulate the heat, but maintenance of mixture proportions essential to surface combustion processes must be automatic and foolproof. This at first, like some of the other questions taken up, looked like a difficult problem, yet it seems to be working out in a thoroughly satisfactory way.

Automatic mixture proportioning has been accomplished by two devices which, working together, carry out the fundamental method; that is, by maintaining equal pressures on an air and a gas orifice, having areas in the desired proportion. Maintaining the air pressure equal to that of the gas, they are brought to a control cock having two ports with areas in the desired proportion; these ports determine the flow to a common mixture outlet, and the proportions will remain constant so long as the principal resistance to the flow of both is in the cock ports. This is accomplished, first, by sufficiently large supply pipes, but it is necessary also that the ports bear a suitable relation to the burner opening, so that while the pressure drop through the burner is large enough to establish the desired velocities for localizing the combustion zone, there is also some drop of pressure through the ports themselves. In other words, the combined areas of the ports in the wide-open position must never be so large as to permit in the mixture chamber a pressure equal to that in the air and gas supply pipes. This does not involve any serious drop through the ports; 0.2 or 0.3 in. of water is ample, and less will do if necessary, but the more there is the more definite the proportioning, and incidentally the smaller the valve needed. To permit adjustment to changes in quality of gas, one port may be made of fixed size and the other adjustable, but in opening and closing both must vary in constant ratio. It is not expected that users will make this adjustment for quality, but

rather the gas men who make installations; and, of course, in any one district the same setting will be found good for the average air requirement of the sort of gas supplied, the variation in which is never large enough to interfere seriously with the operation on this mean setting. Wherever the gas is uniform, or substantially so, in air requirement, this quality adjustment can be eliminated and the ports fixed at the proper ratio, once for all. One successful cock of this sort is shown in Fig. 19. This has two plugs keyed so as to rotate together,

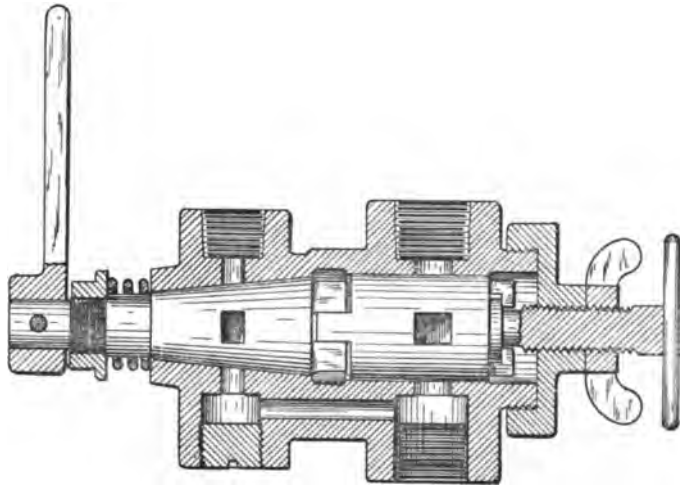

Fig. 19.—Sectional view of double-ported mixing valve, with adjustment for ratio of air to gas.

but otherwise free; one, carrying the small gas port, is tapered and spring seated for tightness, while the other, carrying the air port, is cylindrical, and has an axial adjustment for length of opening. Both plug ports are aligned with the casing ports so as to open and close absolutely together. With this cock, the user regulates the burner exactly as has been customary with common burners controlled by single-ported cocks.

For the satisfactory working of any form of double-ported cock, intended to maintain constant proportions of air and gas, it is necessary that the air and gas approach at equal pressures; and this may be accomplished by regulating the air pressure to that of the gas, or conversely. The former has been found more satisfactory, the air delivered by the fan being passed through a diaphragm regulator carrying a damper valve in the main air passage. This damper is rotated by a crank and connecting rod, fixed to a leather diaphragm, the weight of which is balanced by a spring or dead weight, if

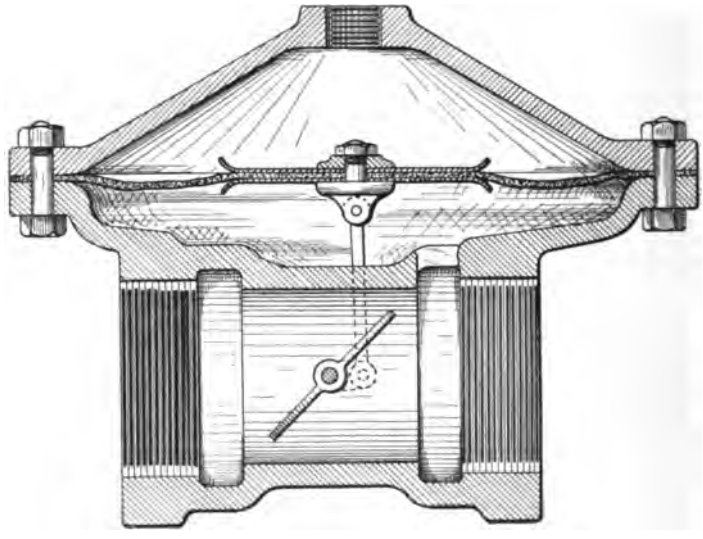

Fig. 20.—Sectional view of air pressure regulator for maintaining air pressure equal to that of gas.

horizontal, but can be neglected if operated in a vertical plane. The delivered air pressure is caused to act on the bottom of the diaphragm while the local gas pressure acts above; both sides being dead ends, that is, not swept by any current, there is little tendency to dry the leather. Changes of gas pressure move the damper to the position of re-equalization promptly and positively, so that, no matter how local gas pressures may vary, the air automatically corresponds and the mixture remains what it should be. The construction of this regulator is shown by Fig. 20.

Air pressure is always necessary for the operation of surface combustion appliances, but the pressure need be no more than is necessary for good regulator action, for which a drop of about 1 in. water is desirable. Such pressures are easily obtainable by fans, preferably electric driven, though not necessarily. If the full available gas pressure be used and this be 3 in., then the fan should deliver at 4 in. of water, but very satisfactory operation can be secured at mixture pressures as low as 1.5 in. for full capacity, which would require less than 2 in. of gas pressure and less than 3 in. fan delivery. At such pressures the power requirements of the fans for ordinary appliances are very small, as may be easily calculated. For small sets the fan efficiency will probably go between 30 and 50%, while the motor efficiency will perhaps average 50%. The power and current requirements are so low that any lamp socket will afford enough capacity to run any domestic appliance, even a large range, and in some cases several appliances operated as a group from one fan.

5. Efficiency of Surface Combustion Appliances Compared with Bunsen.

As in other cases it is here found that the absolute and relative efficiency of surface combustion and bunsen burner appliances is not constant but varies with conditions and, therefore, any discussion must be more or less limited to give a correct impression. For this reason the figures obtained from test will be confined to domestic appliances operating on city gas, such as cook stove top burners, broilers, oven, room and water heaters, all made by removing bunsen burners from standard appliances and substituting new ones. Top burners were tested by taking the consumption of gas and time required to raise a weighed body of water to 200° F., from an initial low temperature, the same or identical vessels, always open, being used in all comparative tests. From a large mass of tests conducted with various bed materials and thicknesses, vessels of different sizes, shapes and materials, different distances between bed or flame and the vessel, at a great variety of gas mixture pressures, at various positions of the cocks, and with various stove tops or burner ring construction, the figures themselves vary so much as to be at first perplexing to one seeking some general conclusion on the relative value of the two systems. Careful analysis, however, reveals

certain conclusions. First, with identical conditions, or as near so as the differences in the systems permit, the surface combustion burners always do an equal amount of heating with less gas than the bunsen, but how much less seems to be dependent on the construction of burner, stove frame and water vessel. Perhaps the most important of these external conditions is the vessel itself, and however queer this may seem at first, an explanation is available. If the vessel be large, of good conducting material, like copper or aluminum, and containing a large amount of cold water, it would approximate the heat absorber of a gas calorimeter, and could take up a very large amount of the heat being generated at a given rate. On the other hand, if the vessel has a small heat absorbing surface in proportion to the rate of combustion, and be made of poor conducting material, then there is less transfer of heat to the water, other things being equal. Size and material of vessel placed over a burner developing heat at a given rate do, therefore, determine to some extent the rate of heat absorption, but also the rate of heat dissipation from its sides, both the submerged and exposed part, and the water surface. This last factor is also more or less influenced by the extent to which the vessel is filled and the air drafts blowing on it. It thus appears that a great deal depends on the vessel and its filling, but as many detailed figures are always confusing, the results of only two vessels are given in this connection. One of these was a cylindrical tinned iron saucepan, about 8 in. diameter and equal height; the other a smaller, tapered, pressed-steel, enameled saucepan, about 6½ in. diamter, both tested on New York City gas, over burners consuming 15 cu. ft. per hr. The bunsen burner was of the Crane construction and the surface-combustion burner had a 4⅜-in. hearth with 5/16 to ⅜-in. material, ½ in. deep, and covered at the edges by a cast-iron ring with vents between it and the vessel ⅛ in. wide. For equal amounts of heat taken up by the water, the relative amount of gas consumed by the Bunsen burner, compared with that consumed by the surface-combustion burner, was 1.44:1 in the case of the large pot, and 1.66:1 with the small pot. With these two burners turned down to a simmer, using the enameled pot, and keeping the water just below the boiling point, as near as could be judged by the eye, the consumptions were for the Bunsen 5.2 cu. ft. per hr., and for

the surface-combustion, 2.42 cu. ft., giving the ratio of 2.15 in favor of the latter.

Assuming a bunsen burner to be consuming 15 cu. ft. per hr., then to give the same heating effect in a cooking vessel, the surface-combustion burner with ratios of 1.8, 1.7, 1.6, 1.5, 1.4 and 1.3, would require 8.3, 8.8, 9.4, 10.0, 10.7 and 11.5 cu. ft. per hr., saving 6.7, 6.2, 5.6, 5.0, 4.3 and 3.5 cu. ft per hr. while doing the same work. The high ratio above reported may not always be actually attained and low values have frequently been found; in one case lower efficiency was noted with a certain surface-combustion burner than with the Bunsen, but this fact pointed out the mistake in construction which, when corrected, afforded high ratios.

It may easily happen that service conditions will arise demanding constructions that are not highly efficient, as, for example, cold cast-iron tops for intermittent service, in the interest of cleanliness, so that any commercial stove construction will probably be a compromise. The best judgment that can now be made is that, taking into consideration all these conditions, a consumption ratio of about 1.55:1, bunsen to flameless, or 1:0.65, flameless to bunsen, may be exepected, which indicates a saving of 35 per cent. of the gas now being used, though it is possible, according to actual tests, that it may be as high as 45 per cent.

It has previously been stated that the expected savings from surface combustion were to be derived, first, from the elimination of the excess air now required of all Bunsen burners, and second, by the superior penetrating power of radiant heat. The influence of these two together is well shown in the preceding relative consumptions, but particularly in the simmering test, where two 15-ft. burners were turned down to keep the water just at a boil for about one hour, which raised the consumption ratio from 1.66 to 2.15. This is a splendid demonstration because, in the turned-down condition, very much more cold air rises with the hot gases of bunsen burners than when they are on full, while there is no change in this respect with the surface-combustion burner.

The direct value of the radiant heat developed by surface-combustion burners is shown most clearly in test of such apparatus as a broiler, or a radiant room heater. Tests have been made in broilers by noting the gas consumption for the

proper cooking of steak and chops, both thick and thin, chicken, squab, fish, lobster, and toast,, under the direction of competent chefs, and comparing with that required for the same operations, in Bunsen-burner broilers. For this purpose the Crane Bunsen broiler was selected, which has cast-iron fingers heated to a dull red by the flame and hence affords more radiant heat than other types not so provided though more commonly used. While results varied in specific instances the general average was very close to a ratio of 2. This means that surface combustion broiling can be done with about half the gas now required on the Bunsen-burner type with feeble radiation, and with less than half that required on others. The quality of the work done is uniformly better, and though opinion differs somewhat here, it has never charged the surface combustion broiler with inferior work. The intense radiant heat which, of course, is under control, permits the food to be placed from 6 to 10 in. away from the burner, promptly sears the outside and prevents the escape of flavoring juices, and not only makes the side that is cooking clearly visible but illuminates it so well that the operation can be perfectly carried on in a dark room.

The gas saving of 50% or better for radiant operations, like the broiling reported above, is confirmed almost identically by tests on a radiant room heater which was compared with the Vulcan, the latter having a perforated cast-iron plate heated a dull to bright red by the heat of a Bunsen bar burner below. Heat was here measured by the rise in temperature of a measured body of water in a flat sheet-metal box placed in front, far enough away to escape contact with any hot gases. For equal amounts of heat thus thrown out, the consumption of the Bunsen is almost exactly twice that of the surface combustion apparatus. It may be said, therefore, that surface combustion domestic appliances can save, in all directly radiant operations, about half the gas required by Bunsen appliances, and in other cases, like top burners and ovens, an average of about 35%, to use a few round numbers derived from actual tests in laboratory and kitchen. The above figures are for continuous operation, and would be reduced in some cases by intermittent work such as involves the lighting of a burner for a few minutes and then turning it out almost as soon as it gets warm. For such service, efficiency is not so

important as a quick heat, and if less time than 1 min. be available, one Bunsen burner can be retained in each stove for that purpose, placing the surface combustion burners where gas savings will be equivalent to appreciable sums of money.

At this point the question naturally arises as to when the saving of gas becomes large enough to pay for the electric current consumed by the fan, and in what time the net saving will pay for the increased cost of surface combustion appliances over Bunsen. The answer to the last question can be found only when it is known how much the appliances will be used, as the fixed charges per hour of use depend on the number of service hours per year, and in this respect the case is similar to plant operation. If a domestic range is to be used one week per year it matters little how efficient it may be, and the cheapest stove available is the one to buy. On the other hand, it will take a very short time to pay for the extra cost of an appliance that is used every day, and doubly so if operated many hours per day, especially if the service requires considerable gas. Calculations could be given for all sorts of hypothetical cases, but as anyone can make them for conditions that are important to him, they are omitted here.

One case is included for illustration. Suppose a domestic range with a full-capacity consumption of 100 cu. ft. per hr. were operated 3 hr. per day and 300 days or 900 operating hours per year, at an average rate of 50 cu. ft. per hr., with such distribution of various burner service as corresponds to an average saving of 40% of what a corresponding Bunsen range would require. It may also be assumed that the latter would cost $35 and the former $50. and that gas costs $1 per 1,000 cu. ft. and electric current 10 c. per kw.-hr. The surface combustion range would consume per year $50 \times 3 \times 300 = 45{,}000$ cu. ft. of gas, while the corresponding Bunsen would consume $45{,}000 \div (1.00—0.4) = 75{,}000$ cu. ft.; the saving of the former over the latter is 30,000 cu. ft., worth $30, per year. From this is to be subtracted the cost of 900 hr. of electrical supply, which must be estimated. For even low efficiencies of fan and motor, not over 0.5 ampere at 110 volts, or 55 watts, should be required. Assuming that no efficient fan and motor be available, and that the absurdly high consumption of 90 watts would be required for the necessary 10 cu. ft. of air per min. at 4 to 5 in. water pressure, the electrical cost

of operation would be $10 \times 0.009 = 0.9$ c. per hr., in round numbers, or \$8.10 per year. This makes the net saving in operation \$30 — \$8.10 = \$21.90 per year, and as the excess of first cost was assumed to be \$15 it would be paid off completely in 600 hr. of operation, or, if uniformly distributed, in 8½ months. One short way of disposing of the electrical cost is to consider that the gas saved by a single top burner will more than pay for the electric current to operate the entire range, so that for all burners in operation, in excess of one, the electrical current costs nothing.

It is hoped that this review of the development of surface combustion will show that it is now possible to design rather than merely invent apparatus, and that such apparatus as commercial conditions may require may now be produced in no more time than is necessary to decide on the models to be manufactured and the production of an initial stock; but there is no intention of leaving the impression that the work of development is finished, for it is only fairly started, and should be continued with corresponding improvement in appliances for the next half century.

RECENT PROGRESS IN METALLOGRAPHY*

BY WILLIAM CAMPELL, PH.D., D.SC.†

The field of metallography during the last 15 years has broadened from a study of the structure of metals and alloys, together with the thermal diagram, until it now embraces the structure and constitution of metals and alloys and their relation to the physical and chemical properties.

We now possess several excellent texts, such as Desch's "Metallography", Gulliver's "Metallic Alloys", Guertler's "Metalographie", and Rosenhain's "Introduction to Physical Metallurgy." The *Internationale Zeitschrift für Metallographie,* edited by Guertler (Borntraeger, Leipzig) is now in its seventh volume, while the *Journal of the Institute of Metals* (London) in its twelfth volume in 1914, devotes much of its space to the science. The abstracts of these two journals cover the whole field of non-ferrous work, the former embracing also the ferrous side, which is also dealt with in the abstracts of the *Journal of the Iron and Steel Institute* (London). The list of books and periodicals given later is not intended to be exhaustive, but contains the chief publications of interest.

To give a complete review of the work in metallography for even the last few years would be a task of considerable difficulty, first because of the enormous mass of material, and secondly because of the impossibility of presenting it logically. It was therefore decided to treat the subject as follows:

1. Metals—Structure and Physical Properties.
2. Binary Alloys—Constitution, Properties.
3. Ternary Alloys—Constitution, Properties.
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Heyn's "Report on the Progress of Metallography during 1909, 1910, and 1911", gives 540 titles, and may be used as a starting point.[1]

1. Metals.

Structure of Metals.—The old ideas of the structure of metals were based on fracture, and from this came the terms: crystalline, granular, fibrous, and amorphous. In general, all metals are crystalline, and the fracture may have no relation to the structure, since it depends not only on the method of breaking but also on the mechanical and thermal treatment. All metals solidify as crystalline grains with distinct orientation, the size and shape depending chiefly on the rate of solidification and the thermal gradient within the freezing mass.

When strained within the elastic limit, the structure shows no change, but when this is passed there is a permanent deformation, and within the grains themselves we find slip-lines and slip-bands, which increase in number and direction as the strain increases, and the grains are distorted and elongated. The elastic limit is greatly increased and the metal becomes harder, but the ducility falls off, as a rule.

On reheating such strained metal, a temperature is reached where the elastic limit and hardness show a rapid falling off and the ducility returns. The grains rearrange themselves and begin to grow with distinct polygonal boundaries, with frequent twinning, the size depending on the temperature and time of annealing, the amount of cold-work the metal has undergone, and upon its cross-section. Copper is annealed at 200°C. (Grard), gold softens above 100°C. (Rose), silver begins to soften after 4 hours at 100° (Hanriot and Lahure), while lead and zinc may soften at ordinary temperatures.

The structure of hot-worked metals consists of polygonal grains, more or less twinned, and closely resembles that of annealed metal. This is due to the fact that there is enough heat present, after distortion of the grains, to cause annealing. In general, the greater the reduction and lower the temperature, the finer the grains. A point is reached where the temperature is too low to cause annealing, the grains remain distorted and cold-work may be said to have begun. This critical

[1]International Association for Testing Materials, Vol. I, 1912. II-I.

temperature varies widely; for tungsten it is over 1300°C., for zinc below 150°C.

Amorphous Theory.—Beilby has shown that in the process of polishing, a thin film of metal actually flows like a liquid, and is apparently an amorphous modification. He has put forward the theory that cold-working of metals produces an amorphous film on the surfaces of slip-planes, which modification is harder and stronger than the original crystalline one. Reheating to the annealing temperature causes the transformation from the amorphous to the crystalline state, and the hardness falls and ducility returns in consequence. Studying the mechanism of intercrystalline cohesion, Rosenhain and Ewen have brought forward the "amorphous cement" theory, which states that the crystals of metals are cemented together by an extremely thin layer of non-crystalline material which has distinct physical properties. The amorphous theory is opposed by Tamman, Heyn, and others.

Strain Disease.—Cohen shows that in cold-worked metals we are dealing with metastable systems. The size of grain can be increased by inoculation from normal metal by means of an etching agent.

Quincke's "Foam-Cell" Hypothesis.—The process of crystallization begins with the separation of the liquid into two immiscible liquid phases. The one which is present in relatively small amounts so arranges itself as to form the walls of "foam-cells", which may be very thin and invisible, filled with the liquid that is present in greater quantity, after the manner frequently seen in immiscible oils and aqueous solutions. These "foam-cells", according to their form and size determine the arrangement of the crystalline particles when actual solidification takes place. Hard drawn wire contains many invisible cylindrical foam walls and therefore possesses great strength. Annealed wire has less strength because, on heating, the viscosity diminishes and foam walls contract to form drops.

Melting-points; Critical Points.—The melting-points of the metals have now been determined with great accuracy, and are given by Burgess. According to Pirani and Meyer, W melts at 3100‡ 60°; Mo, 2450‡ 30°; Ta, 2850°C. According to Ruff Au melts at 1071°; Mn, 1247°; V, 1715°; Cr, 1514°;

alloys. Collected data on several metals and alloys: Cu, Zn, Ni, Al, brass, bronze, Al-bronze, Cu-Ni, and magnalium.

Galy-Aché. Revue de Met., X, 585. Review of recent progress of cold-working.

Baucke. Internat. Jl. Metallog., II (1912), 243. "Uber das Einformen beim Bleimetalle." Recrystallization of cold-worked lead rapid on prolonged etching.

Bardwell. Trans. A.I.M.E., XLIX (1914), 753. "The Annealing of Cold-Rolled Copper." Curves show drop in tensile strength on annealing at 700°F., with rise in elongation to 40% at 800°F. Conductivity similar.

Grard. Revue de Met., VI, 1069. Proc Internat. Assoc. Testing Materials, 1912, II-15. Industrial application of microscopic metallography for controlling the work put on copper and brass. Curves showing effect of cold-work on strength and ductility. Effect of annealing. Structures. Cu, 67/33 and 90/10 brass. Copper annealed at 200°C.

Guillet. Revue de Met., 1913, X, 665. "Recherches sur le recuit des produits écrouis." Temperature of complete annealing independent of amount of cold-work. Ni, 700 to 750°C.; Steel, 700 to 800°; Brass, 350 to 400°C.

Hanriot. Comptes Rendus, 155 (1912), p. 828. "Sur l'écrouissage".

Hanriot. Comptes Rendus, 155 (1912), 971. "Sur l'étirage des metaux." When amount of cold-work is small, great differences in hardness may occur with very slight differences in tensile strength and elongation, but latter properties change suddenly when cold-work exceeds a certain value. Ag, Al, Al-Cu, Cu-Zn.

Hanriot. Revue de Met., X (1913), 595. Mechanical hardening by compression, by tension. Brinell ball of 3 m.m. and 30 kg. Pb not capable of hardening. Work on Ag, Cu, Fe, brass, Al, Zn. Brinell test gives too high readings because of mechanical hardening during test.

Hanriot and Lahure. Comptes Rendus, 158 (1914), pp. 263, 404. Ag softens after 4 hr. at 100°C. Cold-work and annealing on brass and silver. Ball test and tenacity.

Matweef. Revue de Met., VIII, 708. "Sur de recuit des Metaux." Annealing temperature determined by Le Gris' method. Al, Cu, Zn, brass, and Al-bronze.

Robin. Bull. Soc. Ingenieurs Civ., 63 (1910), 523. "Experiences sur l'écrouissage de l'acier et des Metaux industriels." Variation in structure and hardness with temperature of working.

Robin. Comptes Rendus, 155 (1912), 585.

Robin. Revue de Met., X (1913), pp. 722, 758. "Sur le developement des grains des métaux par recuit après écrouissage." Size of grain of Sn, Pb, Al, Cu, Fe, etc., after cold-work and anealing. Influence of impurities on grain growth. Alloys.

Rose. Journal Inst. Metals, X, 150. "On the Annealing of Gold."

Rose. Journal Inst. Metals, VIII, 86. "On Annealing of Coinage Alloys." Work with scleroscope. Temperature at which softening begins and temperature at which it is complete in ½ hr. Au, 80 and 130°. Ag, 80 and 400°. Cu, 275 and 360°. Ni, 300 and 700°. Zn, 15 and 125°. Al, 250 and 400°. Cd, 15 and 150°. Also coinage alloys.

Phelps.Journal Inst. Metals, XII, 125. "Effect of Hydrogen on annealing Gold." Temperature of annealing raised from below 150° to about 300°C.

Timofeef. Comptes Rendus, 155 (1912), 430. Effect of cold-work on cast zinc. Very confused structure by compression. Spontaeous recrystallization begins in a few days at ordinary temperatures. At 100°C. is visible in a few minutes, at 300°C. very coarse. Twins on slight shock.

Timofeef. Revue de Met., 1914, XI, 127. "Sur la recristallization du

zinc ecroui." Specimens cooled in ice during compression, annealed at 65 to 360°C. Velocity of recrystallization depends on temperature and severity of plastic strain.

Haines. Proc. Royal Soc. London, 85 A (1911), 526. Effect of Temperature on Ductility of Zinc.

Trautwine. Proc. Amer. Soc. Testing Materials, XI (1911), 507. "Behaviour of Zinc under Compression."

Rigg and Williams. Proc. Amer. Soc. Testing Materials, XIII (1913), 669. "Strength of Cast Zinc under Compression." Depends primarily on crystallization.

Heyn and Bauer. Internat. Jl. Metallog., I, 16. Über Spannungen in Kaltgereckten Metallen." Measurement of stresses in cold-worked metal. Season cracking, so-called recrystallization.

Heyn. Journal Inst. Metals, XII, 3. "Internal strains in Cold-worked Metals and some Troubles caused thereby."

Faust and Tammann. Zeits. für physik. Chem., 75, 108. "Ein Methode zur Bestimmung der unteren and oberen Elastizitatsgrenze, und über die Verfestigung der Metalle." Al, Cd, Cu, etc.

Properties at High Temperatures

Baumann. Zeits Ver. Deutsch. Ing., 55 (1911), 2016: Stahl und Eisen, 31 (1911), 2108; 32 (1912), 168. Strength and hardness of Al up to 300°C. Microstructure.

Bengough and Hudson. Journal Inst. Metals, XII, 56. "Tensile Properties of Copper at High Temperatures."

Huntington. Journal Inst. Metals, VIII, 126; 234. "Effects of Temperatures higher than Atmospheric on Tensile Tests of Copper and its Alloys."

Structures.

Belaiew. Journal Inst. Metals, XII, 46. "Widmanstatten Structure in Various Alloys and Metals."

Matweef. Revue de Met., XI (1914), 766. "Formation des lignes de Neumann."

Portevin and Durand. Revue de Met., XI (1914), 771. "Sur des lignes de Neumann."

Electrolytic.

Schwarz. Internal. Jl. Metallog., VII, 124. "Metallographische Studien." The structure of electrolytic copper. Very sensitive to strains on handling. Annealing gives new structure. Submitted to antimony vapor the grain structure is revealed by diffusion.

Waser and Kühnel. Elektrchem. Zeits., XVIII (1912), pp. 151, 211.

Waser and Schulz. Elektrchem. Zeits., XVIII (1912, pp. 36, 63. XIX (1913), 304. "Die photographische und mikrophotographische Wiedergabe elektrolytischer Metallniedeschlage." Surfaces of a number of elecrolytically deposited metals described and illustrated.

Tungsten.

Brinslee. Electricity, 69 (1912), 325. Changes in metallic filaments during use.

Coolidge. Jl. Indust. & Engineer. Chem., IV (1912), 2. Some applications of wrought W and Mo.

Coolidge's Patent. Metall. and Chem. Engineering, XII (1914), 108. "Ductile Tungsten Patent."

Erhard. Metallurgie, IX (1912), 441. Manufacture of W.

Fink. Trans. Amer. Electrochem. Soc., 17 (1910), 229; 22 (1912), 400. Some applications of wrought W and Mo.

Forsyth. Astrophys. Jl., 34, 353. Melting-points of Ta and W, 2798 and 3030°C.

Grotthuss-Call. Metall und Erz, X, 844. Wolfram-Thorium, eine duktile Legierung. W with 1% thorium.

Hansen. Brass World, IX (1913), 401. Patent for process of squirting W filaments.
Kruh. Elektro. Masch., 31 (1913), pp. 313, 338. "Uber die Herstellung von gezogenem Wolframdraht." Description and metallographic discussion.
Mennicke. Metallurgy of Tungsten. Kragn, Berlin.
Merrill. Proc. Amer. Inst. Elect. Engineers, 29 (1910), 1433.
Merrill. Jl.Fraklin Inst., 171 (1911), 391. New metallic filament lamps. Ta, W. Structure, strength, testing.
Müller. Zeits. für angew. Chem., XXVI, 404. Review of methods of making filameents, squirting and sintering in H. Hot swaging. Drawn hot through diamond dies.
Patent. Metall. and Chem. Engineering, XII (1914), 480. Schwarzkoph and Burgstaller for ductile W.
Pirani and Meyer. Verhand. Deutsch. Phys. Ges., 14, 426. Melting-points of W and Mo, 3100‡ 60° and 2450‡ 30°. (Same) 13, p. 540; Ta, 2850°C.
Ruder. Jl. Amer. Chem. Soc., 34, 387. Solubility of wrought W and Mo.
Ruff. Zeits. für angewandte Chem., XXV (1912), 1889. Process of making ductile W wires.
Siemens. Jl. Inst. Metals, IX (1913), 42. "Metal Filament Lamps."
Wartenberg. Zeits. für ankewandte Chem., 24, 2243. Melting-point of W.

Binary Alloys.

The thermal diagrams of most of the binary alloys have been worked out and are given in Guertler's "Metallographie", and by Bornemann, Desch, Gulliver and others. The theoretical discussion of the various type diagrams is already well understood, and is presented in the main text-books The determination of the diagrams themselves in many cases, has been faulty, and new work is constantly being done upon them, considerably modifying our original ideas. This is especially true of the changes which take place in the solid state, theoretically discussed by Heyn and others. For example, the alloys of lead and tin, of aluminum and zinc, were long given as examples of the simplest class of binary alloys. Recent researches have shown that the former undergo profound changes in the solid, while the latter, in addition, form a compound by reaction during the process of freezing, which has hitherto escaped detection.

Thermal Diagrams.—Among the references below, one or two papers deserve special mention. Carpenter has shown the similarity between the three series, Ag-Zn, Cu-Zn, and Ag-Cd. Mazzotto's work on Cd-Sn shows a eutectoid at 130°C. and 94.5% Sn. Cobalt alloys have been studied by Waerlert, Ruer and others, while Ruer's work on Cu-Fe shows a new horizontal on the iron branch at 1440°C., similar to that in the Fe-Co alloys.

Konstantinoff and Smirnoff, in the Sb-Sn alloys, show two compounds, SbSn and Sb_2Sn_2. The alloys of silver and gold with tellurium have been studied by Pellini and Quercigh, who found Ag_2Te, AgTe, and $AuTe_2$.

The alloys of carbon with Co, Ni, and Mn have been examined. Cobalt dissolves 3.9% C at 1700° C. which separates as graphite. There is a eutectic at 2.8% C and 1300° C., at which temperature 0.82% C is in solid solution, falling to 0.3% at 1000° C. A carbide has not been detected. Nickel dissolves 6.42% C at 2100° C. (Ni_3C). The carbide is unstable and breaks up into Ni + graphite. There is a eutectic at 1310° C. and 2 to 2.5% C, when Ni holds about 1% C in solid solution.

Joyner has studied the structures of the silver-tin amalgams.

The Cu-Cu_2O diagram has been completed by Slade and Farrow. It resembles Cu-Cu_2S. Mathewson and Stokesbury find that the Ag-Cu_2O series is very similar to that of Cu-Cu_2O. It shows a eutectic of 1.3% Cu_2O at 945° C.

Copper-Zinc.—The brasses, due to their commercial importance, have received a great deal of attention. The original diagram of Shepherd was modified by Carpenter and Edwards, whereby the beta constituent, which occurs from 36 to 60% Zn, undergoes a transformation at 450° C., tending to break down into alpha and gamma, a eutectoid change. The recent work of Hudson seems to indicate that the diagram is even more complex than that given by Carpenter and Edwards.

The physical properties, effect of hot and cold work, and of annealing, and their relation to the microstructure, have been carefully studied by Lohr, Webster, Grard, and others, with the result that we are beginning to see that the relation between structure and properties is very close.

The effect of other metals on typical brasses has been studied, especially in the case of certain so-called "bronzes", e.g., manganese bronze, Tobin bronze, etc., with the result that the new alloys have a much greater strength, yet retain their ductility.

Copper-Tin.—The bronze diagram first worked out by Heycock and Neville, then modified and completed by Shepherd and Blough, has again been under discussion, notably by Hoyt and by Haughton. Much remains to be done before the actual diagram is settled. That part of the diagram embracing the

useful alloys is complete however. As in the case of the brasses, a great deal of study has been devoted to their physical properties, effect of work, and of annealing. The effect of the presence of Cu_4Sn, or delta, is now well understood. The effect of small amounts of other metals has also been studied, notably the alloy 88 Cu, 10 Sn, 2 Zn, or Admiralty bronze, and various phosphor bronzes.

Copper-Aluminum.—These alloys have also received considerable attention, first the copper-rich or "aluminum bronzes", second the light aluminum alloys. The copper end of the diagram is still under discussion. Their properties have been carefully worked out by Carpenter and Edwards in the 8th Report to the Alloys Research Committee. The light alloys for automobile and other work have developed considerably, and we have such alloys as "Duralumin."

Aluminum Alloys.— The Zn-Al alloys, due to their valuable properties, have long been used. Their diagram and properties have been thoroughly investigated by Rosenhain and Archbutt in the 10th Report to the Alloys Research Committee. They discovered a definite compound Al_2Zn_3 which forms by reaction with the melt at 445°C. It decomposes, however, at 256°C. into zinc and the Al-Zn solid solution, which explains some of the peculiarities of Al-Zn castings. The presence of manganese seems helpful, while small amounts of magnesium confer the property of hardening, which appears some time after quenching.

Binary Alloys. Thermal Diagrams.

Guertler. "Text Book of Metallography."
Bornemann. Die Binaren Metallegierungen I and II (1912); also Metallurgie, beginning VI (1909), 236.
Portevin. Work of Tammann's Laboratory on Alloys.

Silver	Alloys.	Revue de Met.,	V, 144
Gold	"	"	182
Aluminum	"	"	274
Copper	"	"	361
Iron	"	"	535
Manganese	"	"	762
Magnesium	"	"	774
Nickel	"	"	838
Lead	"	"	909
Antimony	"	"	VI. 241
Silicon	"	"	951
Tin	"	"	962
Zinc	"	"	975

Ag-Zn. Carpenter & Whitely. Internat. Jl. Metallog., III, 145.
Ag-Zn; Cu-Zn; Ag-Cd. Carpenter. Jl. Metallog., III, 170. All show eutectoid, beta changing into alpha and gamma.

Ag-Cd. Bruni & Quercigh. Zeits. für anorgan. Chem., 68 (1910), 198.
Ag-Cd. Petrenko & Federow. Zeits. für anorgan. Chem., 70 (1911), 157.
Ag-Mn. Arrivaut. Comptes Rendus, 156, 1539. Ag_2Mn at 980°C. forms solid solutions with silver. Two liquids, 20 and 94% Mn. Horizontals, 980 and 1148°C.
Au-Ag. Raydt. Zeitz für anorgan. Chem., 75 (1912), 58. Confirms previous workers.
Au-Cd. Saldau. Intenat. Jl. Metallography, VII, 3. AuCd and $AuCd_2$. Electric conductivity, hardness, diagram and microstructure.
Au-Na. Mathewson. Internat. Jl. Metallog., I, 81.
Ag-Na. Mathewson. Internat. Jl. Metallog., I, 51.
Ag-Na. Quercigh. Zeitz. für anorgan. Chem., 68 (1910), 301.
Bi-Cd. Petrenko & Fedoroff. Internat. Jl. Metallog., VI (1914), 212. Eutectic at 140°C. and 40% Cd. Solid solutions not over 0.1%.
Cd-Sn. Schleicher. Internat. Jl. Metallog..II, 76. Eutectic at 177°CC. and 67.6 atomic percent Sn. Gamma Sn holds a lot of Cd in solution, but precipitates it at 127°C., when gamma transforms to beta tin.
Cd-Sn. Guertler. Idem. pp. 90, 172. From theoretical considerations, alters the eutectoid point.
Cd-Sn. Mazzotto. Internal. Jl. Metallog., IV, 13. Sustains Guertler's conclusions and places the eutectoid at 94.5% Sn and 130°C. Eutectic at 176° and 70% Sn, composed of Cd and Sn (10% Cd in solid solution).
Co-Cu; Co-Ni; Co-Cu-Ni. Waehlert. Zeitz. Ost. Berg. Hütt., 62 (1914), pp. 341, 357, 374. Ni-Co form a series of solid solutions, like Cu-Ni. Cu-Co forms two series of solid solutions, with reaction point like FeCu; have eutectoid at cobalt side; ternary diagram shows freezing surface.
Co-Ni. Ruer and Kaneko. Metallurgie, IX, 419. Smooth curve between Ni, 1451° and Co, 1491°. Curve of disappearance of magnetism is convex upwards, and continues from Ni, 360° to Co, 1102°. Nickel oxide soluble in Ni and gives eutectic like Cu_2O-Cu.
Co-Fe. Ruer and Kaneko. Ferrum, XI, 33. A series of solid solutions with minimum at 35% Fe and 1450°C. The iron branch shows a horizontal with reaction, solid with 14% Co. + liquid 22% = solid 19% Co. at 1490°C. The two branches meet at 1420° C. and pure Fe. Magnetic changes reach maximum at 55% Co, 985°C. = Fe_4Co_3.
Co-Mo. Raydt & Tammann. Zeits. für anorgan. Chem., 83, 246. Compound MoCo, 1484°C. Co. holds 28% Mo in solid solution. Magnetism falls from 1143° (Co) to 760° (25% Mo.)
Co-Mn. Hiege. Zeitz. für anorgan. Chem., 83, 253. A series of solid solutions with a minimum at 1160° C.
Cu-Sb. Carpenter. Internat. Jl. Metallog., IV, 300. Eutectoid changes of Baikow near Cu_3Sb do not exist. Beta transforms to gamma. Solubility of Sb in Cu is 8% at 400°; of Cu in Sb is 0.5%.
Cu-Pb. Friedrich. Metall und Erz, X, 575. The critical temperature for the two conjugate solutions is 1025°C. if left for 15 hr; is 1300°C. ordinarily. At 953°C. the two solutions are 19 and 54% Cu.
Cu-Fe. Ruer & Fick. Ferrum, XI, 39. Curve differs materially from that of Sahmen, Zeits. anorgan. Chem., 57 (1905), 1. The liquidus is horizontal between 26 and 71% Cu. and 1440°C. The Fe branch shows a reaction at 1475°, the three phases being 5, 8 and 13% Cu. Two eutectoids. 810° and 760C.
Fe-Ti. Lamont. Ferrum, XI, 225. Alloys up to 22% Ti. Eutectic at 13% and 1300°C; Fe holds 6% Ti in solid solution. Microphotographs of series; also Nitride of Ti, and ferrotitanium containing carbon.
Fe-P. Konstantinow. Zeits. für anorgan. Chem., 66, 209. Maximum Fe_3P at 1350°C. Fe_2P forms by reaction at 1135°C. Eutectic of Fe (1.7% P) and Fe_2P at 10% P and 1020°C. Undercooling gives eutectic at 945°C.

Ni-Pd. Heinrich. Zeits. für anorgan. Chem., 83, 322. A series of solid solutions with minimum at 1250°C.

Ni-Mo. Baar. Zeits. für anorgan. Chem., 70, 352.

Pb-Sn. Degens. Zeits. für anorgan. Chem., 69, 209.

Pb-Sn. Rosenhain & Tucker. Trans. Royal Soc., London, 209 (1908), 89.

Pb-Sn. Mazzotto. Internat. Jl. Metallog., I, 289. Changes in solid due to chemical changes, according to Degens, and allotropy, according to Rosehain, are really due to change in solubility of Sn with fall of temperature.

Sb-Pt. Friedrich & Leroux. Metallurgie, VI. 1. $PtSb_2$ at maximum. PtSb by reaction. Eutectic of Pt and $PtSb_2$ at 76% Pt and 680°C. Pt_5Sb_2 forms in the solid at 640°C.

Sb-Fe. Kurnokow & Konstantinow. Zeitz. für anorgan. Chem., 58, 1. Revue de Met., VI, 254.

Sb-Fe. Portevin. Revue de Met., VIII (1911), 312. In alloys with 1 to 9% Sb, critical points are not changed. Solid solution up to 6.5% Sb.

Sb-Sn. Konstantinoff & Smirnoff. Jl. Russ. Phys. Chem. Soc., 43 (1911), 1201. Internat. Jl. Metallog., II, 152. Four series of solid solutions, 0 to 10% Sb, SbSn; Sb_3-Sn_2; 90 to 100% Sb. (Atomic percent.) Measurement of electrical conductivity.

Zinc alloys. Arnemann. Metallurgie, VII, 201. Metallography of zinc and zinc-rich alloys.

Zinc-alloys. Curry. Jl. Physical Chem., XIII, 589. Sb-Zn. Sn-Zn shows eutectic from 7 to 99% Zn. Cd-Zn eutectic from 5 to 96% Zn. Pb-Zn, pure Pb and pure Zn. Bi-Zn, bismuth holds 4% zinc in solid solution. Effect of annealing towards equilibrium.

Zn-Fe. Vigouroux, Ducelliez & Bourbon. Bullet. Soc. Chimique, XI (1912), 480. By E.M.F. method, found $FeZn_7$, $FeZn_3$, Fe_3Zn, and Fe_2Zn.

Zn-Fe. Guertler. Internat. Jl. Metallog., I, 353. A study of the structure of galvanized irons.

Calcium alloys. Baar. Zeits. für anorgan. Chem., 70, 352. Alloys with Ag. Cu, Mg, Pb and Tl; also MnTl and MoNi alloys.

Te-Ag; Te-Au. Pellini and Quercigh. Atti Reale Accad. dei Lincei., XIX (1910) (ii), 415-455. Ag_2Te at 959°C. AgTe by reaction at 444°C. Polymorphic change at 412°C., $AuTe_2$ maximum at 464°C.

Te-Cd; Te-Sn. Matsusuke. Zeitz. für anorgan. Chem., 69, 1.

Te-Zn. Kobayshi. Internat. Jl. Metallog., II, 65. TeZn at 1238°., 66% Te, occurs in a groundmass of Te or Zn as case may be.

Te-S. Chikashige. Zeits. für anorgan. Chem., 72, 100.

Co-C. Boecker. Metallurgie, IX (1912), 296.

Co-C. Ruff & Keilig. Zeits. für anorgan. Chem., 88, 410.

Ni-C. Friedrich & Leroux. Metallurgie, VII (1910), 10.

Ni-C. Ruff & Martin. Metallurgie, IX (1912), 143.

Mn-C; Ni-C; Fe-C. Ruff & Bormann. Zeitz für anorgan. Chem., 88; pp. 365, 386, 397.

Frillery. Revue de Met., VIII (1911), 457. On the metallic silicides and study of density of alloys. Preparation in electric furnace. Measurements of density. Microstructures of Al-Si alloys.

Jolibois. Thesis, Paris, 1910: Journal de l'Ecole Polytechnique, 1911. Revue de Met., 1912, 1118. "Recherches sur le phosphore et les phosphures metalliques." Chemical method of isolation. Structures. P;Ni-P;Sn-P;Zn-P. Study of allotrophy and of definite-compounds.

Ag-Hg-Sn. Joyner. Jl. Chem. Soc. London, 99, 195. Amalgams concontaining silver and tin. Study of structure Ag-Hg;Ag-Sn;Hg-Sn and ternary alloys.

Ag-Cu_2O. Mathewson and Stokesbury. Internat. Jl. Metallog., V, 193. Alloys up to 20% Cu_2O are similar to Cu-Cu_2O. Eutectic 1.3% Cu_2O at 945°C. Ref.—Heyn & Bauer, Cu-Sn and O. Zeitz. für anorgan. Chem., 45.52. Otin. Cu_2O-SiO_2. Metallurgie IX, (1912), 92.

Cu-Cu_2O Slade & Farrow. Proc. Royal Soc. London, 87, A (1912), 524.

Copper-Zinc.

Shepherd. Jl. Physical Chem., VIII, 421. Constitution of Cu-Zn alloys.
Tafel. Metallurgie, V (1908), pp. 343, 375, 413. Zn-Cu-Ni alloys and Cu-Ni, Zn-Cu, Zn-Ni.
Carpenter & Edwards. Jl. Inst. Metals, V, 127. A new critical point in Cu-Zn alloys.
Carpenter. Jl. Inst. Metals, VII, 70. Further experiments on the critical point at 470°C. in Cu-Zn alloys.
Carpenter. Jl. Inst. Metals, VIII, 51. The structural resolution of pure Cu-Zn beta constituent into alpha and gamma.
Carpenter. Jl. Inst. Metals, VIII, 59. The effect of other metals on the structure of the beta constituent in Cu-Zn alloys.
Hudson. Jl. Inst. Metals, XII, 89. The Critical Point at 460° in Zn-Cu alloys.

Physical Properties—Annealing.

Bancroft & Lohr. Eighth Intrnat. Congress of Applied Chemistry, 1912.
Lohr. Journal Physical Chem., XVII (1913), 1. Mechanical properties of Cu-Zn alloys.
Bengough & Hudson. Jl. Inst. Metals, IV, 92. Heat treatment of 70/30 Brass.
Guillet. Revue de Met., XI (1914), 1094. "Nouvelles recherches sur les alliages de cuivre et de zinc." Constitution of Cu-Zn, Cu-Sn, Cu-Al, Cu-Ni. Relation to properties. Anomalies of brass. Physical properties 100 to 56% Cu worked out.
Grard. Revue de Met., VI, 1069. "Laiton à Cartouches: à balles." Effect of cold-work and of annealing on physical properties and microstructure of 67/33 and 90/10 brass. Excellent curves.
Johnson. Jl. Inst. Metals, VII 201. Influence of Sn and Pb on microstructure of brass. Sn only slightly soluble in alpha of 70/30 brass as cast. Sn readily soluble in beta of naval brass as cast. Reticulations due to Cu_2Sn from beta have no relation to lead present. Importance of annealing castings 70/29/1 and 62/37/1 before mechanical treatment.
Stead & Steadman. Jl. Inst. Metals, XI, 119. Muntz Metal; correlation of composition, structure, heat-treatment, mechanical properties. References.
Webster. Proc. Amer. Soc. Testing Materials, XIV, 128. Considerations affecting specifications for wrought non-ferrous metals. Curves for physical properties of cold-rolled and annealed brass 0 to 40% Zn. Operations in making sheet. Annealing 0 to 600°C. on physical properties. "Temper."

Copper-Tin.

Heycock & Neville. Phil. Trans. Royal Soc. London, 1897, Vol. 189 A, p. 25. 1904, Vol. 202 A, p. 1.
Shepherd & Blough. Jl. Physical Chem., X (1906), 630.
Giolitti & Tavanti. Gazz. Chim. Ital., 38 (1908), II, 209. Abstracted in Revue de Met., VI (1909), II, 476.
Haughton. Jl. Inst. Metals, March, 1915. Constitution of alloys of Cu and Sn. Gives the four diagrams (see above, and Hoyt). New diagram, 55 to 66% Sn.
Hoyt. Jl. Inst. Metals, X, 235. Internat. Jl. Metallog., VI, 129. On the copper-rich kalchoids. Gives new heat effect 10 to 25% Sn, at 590°C.

Physical Properties—Annealing.

Haughton & Turner. Jl. Inst. Metals, VI, 192. "Volume Changes in
Shepherd & Upton. Jl Physical Chem., IX (1905), 441.

Alloys of Cu with Sn." Apparatus used. Curves of expansion and crystallization interval. Specific gravity and hardness. Microstructure.
Goerens & Dumont. Ferrum, X (1912-13), 21. Influence of annealing on the strength of bronze, Cu 94,Sn 6%. Annealing temperature 315 to 380°C., depending on the amount of cold-work.
Grenet. Comptes Rendus, 151 (1910), 870. Revue de Met., VIII (1911), 108. On tempering bronze. Alloys of 15 and 20% Sn, quenched at 750°C. and drawn at different temperatures. Hardness by Brinell.
Heyn & Bauer. Mitteil . aus dem Kgl. Materialspruf. zu Berlin, 1910, 344. Uber den Einfluss der Warmebehandlung von Bronze auf die Harte.
Portevin & Nussbaumer. Proc. Internat. Assoc. Testing Materials, 1912, III, 4. Note on the wear of bronzes. 8 bronzes used. Brinell hardness. Tested for wear, which varies with delta present.
Portevin & Nussbaumer. Comptes Rendus, 154, 213. Influence of annealing on cold-worked bronze.

Effect of other Metals on Brass and Bronze.

Guillet. Revue de Met., II (1905), 97. "Laiton speciaux."
Guillet. Comptes Rendus, 155 (1912), 1512. Revue de Met., X (1913), 1132. "Les Laitons au Nickel." Cu 50 and 55%. Zn replaced by 0.5 to 10% Ni. Alpha, and alpha + beta types. Physical properties and microstructure.
Dunn & Hudson. Jl. Inst. Metals, XI, 151. Vanadium in brass. Usual structure 50 to 60% Cu, not greatly changed by small amount of Va.
Morris. Jl. Franklin Inst., 171 (1911), 561. Metallurgy of Va. Effect on Cu, on Cu alloys; on 60/40 brass it increases strength and ductility and greatly increases resilience.
Hiorns. Metal Industry, VIII, pp. 82, 119, 166. Modern bronzes. General paper on various bronzes, constitution and physical properties.
Dewrence. Jl Inst. of Metals, XI, 214. "Bronze." Properties at temperatures from 300 to 700°F., of Cu, 88; Sn, 10; Zn, 2; and Cu. 87.5; Sn, 10, Zn, 2; Pb, 0.5%. The first falls off at 375°F. to minimum at 400°F.; the second, containing lead, retains its strength to 550°F., where it showed a maximum ductility.
Guillet & Revillon. Revue de Met., VII, 429. Coefficent of equivalence for special bronzes. Microscopic examination of alloys 85% Cu and 1 to 10% Zn.
Miller. Metallurgie, IX (1912), 63. Influences of various metals on bronze. Physical properties and freezing points.
Primrose. Jl. Inst. of Metals, IX, 158; XII, 254. The heat treatment of Admiralty gun metal.
Robin. Bull. de la Soc. d'Enc., 119 (1913), 12. Microstructure of special bronzes of Al and Sn. "Sur les constituents en aiguilles des alliages." Study of martensitic structure.

Copper—Aluminum.

Carpenter & Edwards. Eighth Report, Alloys Research Committee. Proc. Inst. Mech. Engineers, London, 1907, p. 57.
Curry. Jl. Physical Chemistry, XI (1907), 425.
Gwyer. Zeits. anorgan. Chem., 57 (1908), 113.
Andrew. Institute of Metals, March, 1915. Some experiments of Cu-Al alloys. Suggested new diagram at Cu end.
Edwards. Internat. Jl. Metallog., III, 179. Formation of twin crystals by quenching and its influence upon the hardness of metals. Quenched Cu-Al alloys (9 to 16% Al) twinned; due to pressure set up in quenching. Slip-lines and amorphous phase formed.
Hanemann & Merica. Internat. Jl. Metallog., IV, 209. The structure of alloys 10 to 16% Al, martensitic on quenching.
Portevin. Internat. Jl. Metallog., IV., 257. The decomposition of beta into the eutectoid.
Portevin & Arnou. Comptes Rendus, 154 (1912), 511. 10 to 11% Al. Effect of annealing on martensitic structure.

Read. Jl. Inst. Metals, X, 344. Influence of phosphorus on some Cu-Al alloys. Al, 10 and 5%, P, 0.03 to 0.2%. Tensile tests, hardness, conductivity, corrosion, structure.

Aluminum Alloys.

Lorenz & Plumbridge. Zeits. für anorgan. Chem., 83 (1913), 243. Al-Sn. No solid solutions. Eutectic at 98 atomic percent Sn confirms Gwyer. (Zeits. anorgan. Chem., 69, 311).

Rosenhain & Archbutt. Tenth Report, Alloys Research Committee. Proc. Inst. Mech. Engs. (London), 1912, 319 to 515. Al-Zn: Constitution, Mechanical properties. Appendix on alloy of Al 72, Zn 25, Cu 3%.

Rosenhain & Archbutt. Jl. Inst. of Metals, VI, 236. Al-Zn diagram and constitution.

Bancroft. Foundry, 1910, 268. Revue de Met., VIII (1911), 735. Al-Zn: Tensile strength and elongation curves. Contrast with Carpenter's results.

Ewen & Turner. Jl. Inst. Metals, IV (1910), 128. "Shrinkage of Pb-Sb and Al-Zn alloys." Gives expansion, tensile and ductility curves. A new heat effect at 250° up to 56% Al. Maximum at 17% Al. Corresponds to $AlZn_2$.

Portevin. Revue de Met., VIII (1911), 721. Al-Zn alloys: Physical properties as sand-cast; forged, 0 to 20% Zinc.

Czako. Comptes Rendus, 156 (1913), 140. Al-Va: Compound Al_3V (= 34.5%) appears at 1% Va. Also AlV and AlV_3. Aluminothermic alloys.

Chouriquine. Revue de Met., IX (1912), 874. Pt-Al alloys. Al_3Pt at 787°C.

Various Aluminum Alloys.

Read & Greaves. Inst. of Metals, March, 1915. "Properties of some Ni-Al and Cu-Ni-Al alloys." Al-rich alloys.

Wilm. Metallurgie, VIII (1911), 225. "Magnesium-bearing Aluminum Alloys." Change in alloys with 0.5% or more Mg after quenching from 500°C. Effect of Cu,Mn,Ni, etc., "Duralumin."

Cohn. Verh. Ver. Gewerbfl., 1910, 643. Stahl und Eisen, 31 (1911), 157. "On Duralumin."

Levi-Malvano & Marantonio. Gazz. Chim. Ital., XLII (1), 353. Light aluminum alloys. 2% Cu, 10 to 20% Zn, homogeneous. 6.8 or 10% Cu, 10 or 4% Zn show two constituents. Eutectic structure appears only in alloys very rich in zinc.

Schirmeister. Metallurgie, VIII (1911), 650. "On light Alloys of Al and Co.

————. Elektrochem. Zeits., XX (1914), 295. 9 to 12% Co gives good castings; less corroded than Al. Are coarsely crystalline and low tensile strength. Addition of W or Mo improves structure. 9 to 10% Co, 0.8 to 1.2% W. or 0.6 to 1% Mo gives forgeable alloys with three times strength of Al.

————. Elektrochem. Zeits., XX (1914), 264. For motor industry, alloy of 87 Al, 8 Cu, 5 Sn better than with zinc for casting and working properties. Duralumin, Cu, 5%; Mg, 0.25 to 0.5%; Mn, 0.5 to 0.8%.

————. Metaux et Alliages. VII (1914), 5. Light aluminum alloys. Study of Al-Zn diagram. 25% Zn alloy, for tenacity and lightness. 40% Zn for sand cast, and 50% for chill castings. Mn-Cu-Al alloy, 3% Cu; 1% Mn. Properties of 25% Zn, 3% Cu given. (See Rosenhain & Archbutt).

McAdams. Metall. and Chem. Engineering, XII (1913), 658. Patent Alloy. Al five times weight of zinc, and zinc five times weight of copper. Very malleable. (Al, 80.6; Zn, 16.1; Cu, 3.2%).

Aluminum solder. Metall and Chem. Engineering. X, 309, 557; XI, 197; XII, 66, 352.

Heat-Treatment, Annealing. Properties at High Temperature, Etc.

A general review of the subject of heat-treatment is given by Portevin, who points out that it depends on the tendency to return to a state of mechanical, chemical, or crystalline equilibrium. Cold-worked alloys rearrange their distorted constituents on annealing, while those whose rate of freezing or of cooling was such that they were in a state of metastable equilibrium tend to become stable. Non-homogeneous grains of a solid solution become homogeneous, often dissolving a second constituent up to their saturation point, as in the case of gun-metal, where delta disappears on annealing.

The annealing of brass and bronze has already been referred to. Rose has investigated the heat-treatment of the alloys used in coinage; Webster worked on monel metal, aluminum bronze, cupro-nickel, brass, etc.

The change in strength and ductibility of alloys when heated has been studied by several investigators. Huntington found that while the tensile strength falls off directly with the temperature, for bronze the elongation and reduction of area take a dip at 400°F., with a minimum between 600° and 700°F. For brass, the elastic limit shows a maximum of 400°F., the elongation a maximum at 500°F., at which point the reduction of area begins to dip. For copper-nickel, the elongation begins to dip at 400°F. and the reduction of area shows a maximum at 350°F. For copper-aluminum, the elastic limit rises slightly to 800°F. and then falls; the elongation takes a sharp dip at 400°F. to a minimum at 800°F. The reduction of area slowly falls to 400° then sharply, with a minimum at 800°F.

The process of cementation or diffusion in the solid has had considerable study in iron and steel. Bruni has studied the diffusion of copper into nickel, and into gold, also silver into gold to form solid solutions. Conditions were studied by measuring the change in electrical conductivity. Diffusion of copper and zinc is considered by Hudson, in his work on the critical point at 460°C.

The behavior of alloys when heated in vacuo has been dealt with by Turner and others, more especially the brasses. When zinc is present in amounts of less than 40%, it can be distilled off, leaving all the copper behind.

The autogeneous welding of alloys has been studied by Carnevalli. In copper the capacity to resist fracture is reduced 50%, brittleness increases 30%, the ductility falls to one-tenth of the original. In brass and bronze, the deficiency in mechanical properties is greatly intensified as the number and variety of constituents increase. While mechanical treatment of the weld causes no improvement, heat treatment is beneficial, especially slow-cooling. Loss of tin and zinc is large, and oxides dissolve in the metal. For aluminum a coarse crystallization results, inducing brittleness. Hammering and reheating to 500°C gives great improvement.

Annealing, Etc.

Portevin. Revue de Met., X, 677. Effect of annealing on the structure of alloys reviewed. (a) return to mechanical equilibrium; (b) return to physico-chemical equilibrium; (c) return to crystalline equilibrium. Relation to equilibrium diagram.

Andrew. Internat. Jl. Metallog., VI, 30. Hardness of metals. Some slowly cooled alloys are harder than when quenched as one solid solution. Cu-Al. Cu-Sn. Cu-Zn. Nickel and manganese steels. Hardness of steel due to martensite, a fine mixture of Fe_3C in a matrix of austenite with a small amount of alpha iron.

Bengough & Hudson. Jl. Inst. Metals, I, 89.
Muntz metal; bronzes. Effect of annealing on the physical properties and structure. Constitution of brasses, bronzes and Cu-Al alloys. References.

Guillet. Bullet. Soc. Ingen. Civ., 63, 547. "Remarques sur l'écrouissage". Influence of cold-work in the mechanical properties and relation of working to the critical points. Cu, steel, Al-Cu, Cu-Ni, Cu-Sn, Cu-Zn.

Rose. Jl. Inst. Metals, VIII, 86.
"On the annealing of coinage alloys". Temperature at which softening begins and temperature at which it is complete in ½ hr. as follows: Gold-copper, 290 to 300, and 500°. Silver-copper, 230 to 300° and 550 to 700°. Coinage bronze, 200 and 470°. Copper-nickel 300 and 650°C.

Webster. Proc. Internat. Asso. Testing Materials, 1912, VII, 6. Effect of cold-working on the physical properties of metals. Monel metal; Al bronze; Ag; cartridge metal; cupronickel; copper rod; brass rod; 97/3 brass. Curves show relation between percentage reduction and physical properties.

Properties at High Temperature, Etc.

Bengough. Jl. Inst. Metals, VII, 123. "A study of the properties of alloys at high temperatures". Ref. to previous work. Describes electric furnace used to heat tensile-test specimens. Study of (1) pure metals, Cu, Al; (2) solid solutions, Ni-Cu and 70/30 brass; (3) complex; muntz metal.

Huntington. Jl. Inst. Metals, VIII, 126. Effect of temperatures on Cu and its alloys. Pure Cu; arsenical Cu; Cu-Sn; Cu-Ni; Cu-Zn; Cu-Al; wrought iron; and mild steel. Surves showing changes in tensile strength, Elastic limit, reduction of area and elongation.

———— Metall. and Chem. Engineering, X (1912), 160. Gives diagram showing tensile strength of monel metal, manganese bronze, steel and copper up to 675°C.

Bregowsky & Spring. Proc. Internat. Assoc. Testing Materials (1912), VII, 1. Effect of high temperatures on the physical properties of

some alloys. Tensile and torsion tests 70 to 1000°F. on iron, steel, bronze, brass, monel metal.

Guillet & Bernard. Comptes Rendus, 157, 584. Shock tests at different temperatures, on bronze and brass show decided brittleness in neighborhood of 200 to 300°C. Lead greatly increases brittleness.

Bruni & Meneghini. Internat. Jl. Metallog., II, 26. Formation of Metallic solid solutions through diffusion in the solid. Cu-Ni; Cu-Au; Ag-Au. Wires of Ni and Au coated electroytically, then heated. Formation of solid solutions followed by measuring electric conductivity.

Guillet & Bernard. Revue de Met., XI (1914), 752. "Les reserves en cementation et la diffusion dans les solides." Diffusion of copper in steel in cementation, brass, bronze, etc.

Turner, Jl. Inst. Metls, VII, 105. "Behavior of certain metals when heated in vacuo." Brass: zinc entirely volatilized; copper remains up to about 1200°C. Poisoned brass (Cu 72-5, Zn 11.5, Pb 7, Sn 5.5, Fe 2): the zinc and lead distilled. Hard zinc (Fe 4.7, Pb 0.81): at 500°C. no iron goes over; at 550°C. 1.29 iron goes over. Zinc begins to votalize at 375 to 380°C. At 520°C. zinc vapor given off by 60/40 brass; at 550°C. by 70/30 brass.

Groves & Turner, Jl. Chem. Soc. London, 91, 585. "Behavior of alloys when heated in vacuo." Makes five classes, when heated up to 1200°C. in vacuo. Both metals non-volatile: Cu-Al, Cu-Ni, Cu-Sn, Cu-Fe. Volatile metal quantitatively removed; Cu-Bi, Cu-Pb, Cu-Zn, Fe-Zn, Pb-Sn. Chemical Compound remains: Au Zn, Cu_2Sb, Au-Cd, $Mg-Zn_2$, etc.

Thornycroft & Turner. Jl. Inst. of Metals, XII, 214. "Behavior of Cu-Zn alloys when heated in a vacuum." Alloys containing more than 40% Cu can be separated into their constituent metals, while with alloys with less than 40% Cu, part of the Cu is volatilized with the zinc. Alloys with high percentage of zinc somewhat more volatile than pure zinc.

Karr. Trans. American Brass Founders Assoc., V (1911), 78. Pouring and melting-points of some high-grade bronzes.

Guillet & Norton. U. S. Bureau of Mines. Technical Paper No. 60. Metal Industry, 1913, p. 514. Melting-points of commercial brasses and bronzes.

Tucker. Jl. Inst. Metals, VIII, 258. "Joining of Metals." General discussion (1) by metallic cement; (2) by autogeneous fusing; (3) by use of cementing metal under pressure.

Carnivali. Jl. Inst. Metals, VIII, 282. "Autogeneous welding of copper and its alloys, and of aluminum."

3. Ternary Alloys.

The ternary systems are now being extensively investigated. The ternary diagrams have been theoretically discussed by Heyn, Geer, Janecke, etc. Many investigators express composition in atomic percentage while the majority use percent by weight. Graphic methods of conversion from one system into the other have been published by Hoffmann, affording a great saving of time.

A great deal has been accomplished during the last few years in unravelling the constitution of ternary alloys. Tafel worked out the Cu-Ni-Zn diagram, applied to the German silvers; Hudson and Law the phosphor-bronzes; Hoyt the cop-

per-rich kalchoids; Giolitti and Marantonio the plastic bronzes; Edwards and Andrews the Cu-Sn-Al diagram and properties.

Other systems have been investigated in part, as the copper end of the Cu-Zn-Al diagram by Carpenter and Edwards; of the Cu-Al-Ni by Read and Graves; of the Cu-Al-Mn by Rosenhain and Lantsberry.

The Pb-Sb-Sn system has been worked out by Loebe and by Campbell, who also investigated the tin end of the Sn-Sb-Cu series. In this connection the work of Heyn and Bauer at Grosse Lichtefelde West is to be emphasized.

Industrially, the Ag-Zn-Pb series is of importance, as bearing on the Parkes process of desilverizing. It has been worked out by Kremann and Hoffmeier, who find the removal of zinc due to formation of Ag_2Zn_5 and not to the freezing of the zinc itself.

The importance of the formation of solid solutions in engineering alloys has often been emphasized. A number of ternary alloys are made up entirely or in part of solid solutions. Parravano and his associates have investigated the ternaries of Fe, Mn, Ni, and Cu; also the quarternary series. The German silvers are also an example. Vogel has worked on the Fe-Ni-Cu alloys, and Waehlert on the system Co-Ni-Cu.

Ternary Systems—Theoretical

Geer. Jl. Physical Chemistry, VIII, 257. Crystallization in three component systems.
Jenecke. Metallurgie, VII (1910), 510. Isomorphie ternaren Mischungen bei Vorhandensein von Mischungslücken.
Loebe. Metallurgie, VIII (1911), 7. Uber die Konstitution der ternaren. Legierungen (Pb-Sb-Sn).
Sahmen. Zeits für physik. Chem., 59 (1907), 257. Uber die Anwendung der thermischen Analysis auf Dreistoff System. Idem. 79 (1912) 421. uber ternare Mischkristalle.
Schreinemakers. Zeits. für physik. Chem.: 50, 169; 51, 547; 52, 513. Mischkristalle im Systemen dreier Stoffe.
Tammann. Lehrbuch der Metallographie (1914), p. 353.
Vegesack. Zeits. für anorgan. Chem., 54, 367. The ternary alloys of Pb, Mg, & Sn.
Hoffmann. Metallurgie, IX (1912), 133. Graphic method of converting weight percent into atomic percent.
Parravano & Sirovich. Atti. della Reale Accad. dei Lencei (1911), XX, pp. 206, 331, 412. Tetrahedral equilibrium. Diagrams of quaternary systems.

Ternary Alloys.

Cu-Ni-Zn. Tafel. Metallurgie, V, pp. 343, 357, 413. Diagram worked out.
German silver. Hudson. Jl. Inst. Metals, IX, 109. Microstructure.
Thompson, Trans. Chem. Soc. London, 105 (1914), 2342.

Cu-Sn-P. Hudson & Law. Jl. Inst. Metals, III, 161. Contribution to study of phosphor-bronze. The ternary diagram given for Cu-Cu_3P-Cu_3Sn.

Cu-Sn-P. Levi-Malvano & Orofino. Gazz. Chim. Ital.., 41 (1911), II, 297. The Cu_3P-Cu_3Sn diagram, and the ternary system.

Cu-Sn-Zn. Hoyt. Jl. Inst. Metals, X, 235. Internat. Jl. Metallog., VI, 129. On the copper-rich kalchords.

Cu-Sn-Pb. Giolitti & Marantonio. Gazz. Chim. Ital., 40, 51. Worked out diagram 0 to 20% Pb, 0 to 25% Sn.

Cu-Sn-Al. Edwards & Andrews. Jl. Inst. Metals, II, 29. Constitution and properties. Ternary diagram. No ternary compound. Inversion of Cu_3Al at 540° into alpha and gamma accelerated by addition of Sn (See Proc. Royal Soc. London, 83A, 568.)

Cu-Zn-Al. Carpenter & Edwards. Internat. Jl. Metallog., II (1912), 210. Alloys up to 16% Al and 60% Zn worked out.

Cu-Ni-Al. Guillet. Comptes Rendus, 158 (1914), 704. Three series of alloys 60, 83, and 90% Cu; Al from 0 to 9.7%. Physical properties and microstructure same as Cu-Al binary for Ni replaces Cu.

Cu-Al-Ni. Read & Graves. Jl. Inst. Metals, XI, 169. Physical properties and microstructure of series: 1, 5, 10% Al, with 1, 5, 10 and 15% Ni.

Cu-Al-Mn. Rosenhain & Lantsberry. 9th Report. Alloys Research Committee, Proc. Inst. Mech. Engineers, London (1910), 119 to 339. Copper-rich alloys up to 11% Al and 10% Mn. Physical properties and microstructure.

Al-Cu-Zn. Levi-Malvano & Marantonio. Gazz. Chim. Ital., 41 (1911). (II), 282. Binary Cu_3Al-Zn. Freezing-point surface Cu-Cu_3Al-Zn.

Al-Cu-Zn. Levi-Malvano & Marantonio. Gazz. Chim. Ital., 42 (1912), 353. Ternary Cu_3Al-Al-Zn.

Mg-Al-Zn. Eger. Internat. Jl. Metallog., IV, 29. Binary Al_3Mg_4-Zn_2Mg. The ternary diagram. Characteristic properties of alloys.

Fe-Ni-Mn. Parravano. Gazz. Chim. Ital., 42 (1912), II, 367. A series of solid solutions.

Ni-Mn-Cu. Ibid, p. 385. A single series of solid solutions.

Fe-Mn-Cu. Parravano. Gazz. Chim. Ital., 42 (1912), II, 513. (See Internat. Jl. Metallog., IV, 171). Part of this diagram shows two solid solutions.

Fe-Mn-Cu-Ni. Parravano. Gazz. Chim. Ital., 42 (1912), 589. The quaternary series.

Sn-Cd-Zn. Lorenz & Blumbridge. Zeits. für anorgan. Chem., 83. 228. The binaries. Ternary eutectic at 73.8 Zn; 25.4 Cd; 3.7 Zn (atomic %) at 164°C.

Bi-Cd-Zn. Mathewson & Scott. Internat. Jl. Metallog., V, 1. Ternary eutectic. 44.3 Bi, 54.1 Cd, 1.6 Zn (atomic %) at 143°C.

Bi-Cd-Pb. Barlow. Zeits. für anorgan. Chem., 70, 178. Jl. Am. Chem. Soc., 32, 1390. Gives thermal diagram of binaries and of ternary.

Pb-Bi-Sn-Cd. Parravano & Sirovich. Gazz. Chim. Ital., 42 (1912), I, 630. Quarternary eutectic, 49.5 Bi, 27.27 Pb, 13.13 Sn, 10.1% Cd.

Au-Ag-Cu. Janecke. Metallurgie, VIII (1911), 597. Eutectiferous in part

Ag-Cu-Ni. de Cesaris. Gazz. Chim. Ital., 43 (1913), 365.

Au-Ag-Ni. Ibid, p. 586.

Au-Cu-Ni. Ibid, 44 (1914), 27.

Ag-Sn-Pb. Parravano. Internat. Jl. Metallog., I, 89. Four surfaces, Ag, Ag_3Sn, Sn, and Pb. Reaction at 300°C. near Ag-Pb binary (2% Sn.) Ternary eutectic near Sn-Pb binary. Contains Sn, 63.4%, Pb 35.6%, Ag 1%; 174°C.

Ag-Sn-Pb. Parravano. Internat. Jl. Metallog., III, 15. Theoretical discussion.

Ag-Zn-Pb. Kremann & Hoffmeier. Monats hefte für Chemie., 32 (1911), 563, 597. The ternary diagram divided into five systems; Pb, Zn,

Ag Sn, Ag_3Zn_8, Ag_2Zn_3, Ag Zn, Ag_2Zn_3; Parkes' Process. Removal of zinc due to removal of Ag_2Zn_3.

Ag-Zn-Pb. Bogitch. Comptes Rendus, 159 (1914), 178. Melts made and layers analyzed.

Pb-Sn-Zn. Levi-Malvano & Ceccarelli. Gazz. Chim. Ital., 41 (1911) (II), 269, 314. Eutectic at 177°C. and 71% Sn, 24% Pb, 5% Zn. Hardness by Brinel test.

Pb-Cd-Hg. Janecke. Zeits. für physikal Chem., 73, 328.

Cu-Cd-Sb. Schleicher. Internat. Jl. Metallog., III, 102. Shows binary sections, Cu_2Sb-CdSb; Cu_2Cd_3-Cd_3Sb_2; Cu_2Cd-Cu_2Sb. Ternary systems $SbCu_2$-SbCd-Cd more closely studied. Metastability of SbCd persists in these alloys.

Bi-Cu-Sb. Parravano & Viviani. Rend. Acc. Lincei., 19 (1910), I, 835. II, pp. 69, 197, 243, 343.

Bi-Cu-Sb. Parravano. Gazz. Chim. Ital., 40 (1910), II, 445.

Co-Ni-Cu. Waehlert. Oster. Zeits. für Berg. und Huttenwesen, 62 (1914), pp. 341, 361, 375, 392, 406.

Fe-Ni-Cu. Vogel. Zeits. für anorgan. Chem., 67, 1.

Cu-Pb-Ag. Friedrich & Leroux. Metallurgie, IV, 293. Eutectic at 302°C. and 2% Ag, 0.5% Cu, 97.5% Pb.

Mg-Cd-Zn. Bruni, Sandonnini & Quercigh. Zeits. für anorgan. Chem., 68, p. 73, and 78 (1912), p. 273.

Pb-Sb-Sn. Loebe. Metallurgie, VIII (1911), 7. The ternary diagram worked out completely. Theory discussed.

Pb-Sb-Sn. Campbell and Elder. School of Mines Quarterly 1911, 32, p.244

Pb-Sb-Sn. Campbell. Metallurgie, IX (1912), 422. Location of Pb-SbSn-Sn reaction point fixed.

Sn-Sb-Cu and Pb-Sb-Sn. Campbell Proc. Am. Soc. Testing Materials, XIII, 630. Useful Sn-Sb-Cu alloys discussed; constitution. Pb-Sb-Sn diagram. Typical alloys.

Cu-Pb-Sn. Carnevali. Rend. Soc. Chim. Ital., (2) 3, (1911) 76. Researches on anti-fraction metals. I.

Bearing Metals, Etc.

Hague. Engineering, 89 (1910), 826. Summary of properties and structures: (1) Rigid bronzes; (2) Plastic bronzes; (3) White metals.

Heyn & Bauer. Verhand. Ver. Beford. Gewerbefi., 1914, 235. Pb-Sn-Sn; Cu-Pb-Sb-Sn; constitution and properties.

Heyn & Bauer. Kgl. Materials-prufungsamt, 29 (1911), 29. Cu-Sb-Sn.

Heyn & Bauer. Kgl. Materials-prufungsamt, 29 (1911), 63. Cu-Sn-Zn. As-Cu-Sn-Zn; Lagermetalle; Weismetalle; Rotguss.

Schafer. Zeits. Prakt. Masch. Bau., 1913, III. Metall. and Erz., X, 470. Uber Lager-weiss-metalle. Pb-Sb-Sn + Cu and Ni. Microscopic examination.

Smith. Engineering, 91, 171. Some tests on anti-friction metals.

4. Miscellaneous.

Faust. Zeits. Elektrochem., 18 (1912), 430. "Allegemeines Verhalten der binaren Metallegierungen." Metallographic research, 1909-1912.

Rosenhain. Jl. Inst. Metals, 1, 200. "Metallographic Investigations on Alloys." General paper. References.

Bragg. Metal Industry, IX, 26. "The Microscope and the Brass Foundry."

Guertler. Giesserei Zeitung, IX (1912)), pp. 137, 177. "Use of equilibrium diagrams in the foundry." Diagrams and microstructure.

Primrose, Jl Inst. Metals, IV, 248. "Metallography as an Aid to the Brass Founder."

Revillon. Bull. Soc. d'Encourage., 110 (1911), 362. Application of certain modern methods of testing copper alloys. Tensile, hardness, shock.

Webbert. Proc. Amer. Soc. Testing Materials, XIV, 146. Strength of non-ferrous castings; comparison of different test-specimens. (1) 88/10/2 bronze type; (2) manganese bronze type. 10 alloys. Types of test specimens used and effect on physical properties.

Wyss. Ferrum, X (1913), 167, 207. "Uber den Verlauf der Biegungsfestigkeit, der Dehnung, des Spezifischen Gewichtes und der Harte in gegossen Staben aus Aluminum, Gusseisen und Bronze," Mechanical and physical properties for several cast metals; pure Al; alloy with 8% Zn; 1.5% Cu; tin bronze; and cast iron.

Irresberger. Stahl und Eisen, 33 (1912), pp. 1279, 1612, 1984. Abstracts on Cu, bronze, brass, Al, Al alloys, bearing metals, german silver; references.

Kloss. Geisserei Zeitung, VIII (1911), pp. 9, 46, 74, 117, 141, 173, 240, 272. Aus der Metallgiessereipraxis. Die Kupfer-Zinnlegierungen.

Hudson. Jl. Inst. Metals, March, 1915. Etching Reagents and their application: (a) non-ferrous; (b) ferrous. Collected from original sources.

Le Gris. Revue de Met., VIII, 613. "Sur les filiations d'alliages metalliques." Diffusion alloys: Pb-Sb, Ag-Sb, Sb-Sn, Sn-Sb-Cu, Sb-Pb-Sn. Hardness test of Le Gris, and microstructure.

Le Chatelier. Internat. Assoc. Testing Materials, 1912, II, 12. Alloys by super-position.

Gulliver. Jl. Inst. Metals, IX, 120; XI, 250; and March, 1915. Quantitative effect of rapid cooling, upon the constitution of binary alloys. I refers to Pb-Sn. II to Cu-Sn, Cu-Zn, Cu-Ni. Obtains a close determination of proportion of liquid present in a quickly cooled alloy in cases where liquidus and solidus are considerably curved.

Gulliver. Proc. Royal Soc. Edinburgh, 32 (1912), 36. The structure of ternary alloys. May have two kinds of primary crystals in contact with ternary eutectic. Due to segregation. Bi attracts Bi of binary and Sn migrates and forms skeletons. Cu-Sb-Pb alloys show copper antimonide and Sb.

Vogel. Zeits. für anorgan Chem., 76 (1912), 425. Structure of eutectics. The two components crystallize simultaneously and not alternately. Growth perpendicular to the cooling surface or radially from centers of crystallization; e.g., Zn-Cd.

Lampough & Scott. Proc. Royal Soc., London, XC (1914). A, 600. Growth of eutectics. Halos on primary crystals due to segregation and not to undercooling.

Kaiser. Metallurgie, VIII (1911), pp. 258, 296. Compositions of technical alloys. Some 900 alloys with trade names catalogued.

Hughes. Jl. Inst. Metals, VI, 74. Non-ferrous metals in railroad work; copper, arsenical copper. Physical properties 0-650°F. Copper alloys, white metals. Gives table of analyses (p. 113).

Haynes. Brass World, IX, pp. 21, 159. Cobalt-chrome alloys. Original stellite Co, 75, Cr, 25%. For lathe tools Co 60, Cr 15, W 25. For high-speed, Co 55, Cr 15, W 25, Mo 5. Alloy, Co 45, Cr 15, Mo 40, is very hard and cuts glass easily.

Kloss. Giesserei Zeitung, IX (1912), pp. 347, 410. "Uber Neusilber und ahnliche Legierungen." English and German methods of manufacture. Composition; solders: Soft, Cu 4.5; Zn 7.0; Ni 1.0. Medium, Cu 35; Zn 56.5; Ni 9.5. Hard, Cu 40; Zn 50; Ni 14.

————. Iron and Coal Trade Review, 88 (1914), 994. Standard bearings for British railway wagons. "Brass," Cu 84 to 88; Sn 10 to 12; Zn 2 to 4. "White Metal," Sn 60; Pb 22; Sb 12; Cu 6.

————. Engineering, XCV (1913), 99. Alloys for motor cars. Radiator castings, Al 88 to 86, Cu 12 to 14. Gear cases, Al with Zn 9 to 11, Cu 1.9 to 2.2. "Brasses," Cu 76, Zn 20, Sn 3, Pb 1. Bearings for crank shaft, Sn 78, Sb 12, Cu 10. Micrographs.

Thompson. Eng. and Min. Jl., 91 (1911), 223. Monel metal and its uses.

Friedrich. Metallurgie, IX, pp. 41, 81. Das Metallhüttenmanische Institut der Kgl. Tech. Hochschule zu. Breslau.
Guertler. Internat. Jl. Metallog., IV, 327. Vessels, fluxes and atmosphere for metallographic laboratory work. Gives table.

5. Electrical and Magnetic Properties.

The relation of the various physical properties to the thermal diagram has been emphasized frequently. Electric conductivity, hardness, specific weight, etc., have all been studied more or less and the general form of their curves is known. The study of the constitution of a binary series from its electrical conductivity has been emphasized by Guertler, while different specific binary series have been investigated by Ledoux, (Cu-Sn), Pushin, (Cu-Sn and Cu-As), Norsa (Cu-Zn), and Broniewski (Al alloys).

A new field of investigation has been opened by Bornemann and his co-workers. The electric conductivity of alloys in the liquid state has been worked out for many binaries. Now this method is being used to plot equilibrium diagrams for those alloys which are only partially miscible in the liquid state. The critical temperature can be accurately determined.

Electrical Properties

Bornemann & Müller. Metallurgie, VII, 396. Müller. Metallurgie, VII, 755. Electric conductivity of alloys in the liquid state.
Bornemann & Rauschenplat. Metallurgie, IX, pp. 474, 505. Electric conductivity of liquid alloys. Cu-Ni curve is smooth with minimum. Cu-Sb has sharp minimum at Cu_3Sb.
Bornemann & Wagenmann. Ferrum, XI (1914), 276. Electric conductivity of liquid alloys used to plot equilibrium diagram, especially the 2-liquid region; e.g., Cu-Pb; Cu-Cu_2S; Cu_2S-Fe S; Cu_3 Sn, Cu_2Zn_3; Cu_2Cd_3; $CuAl_2$; Cu_2Al.
Guertler. Jl. Inst. Metals, VI, 135. Electric conductivity and the constitution of alloys.
Guertler. Zeits. für Elektrochem., 18 (1915), 601.
Broniewski. Internat. Assoc. Testing Materials (1912), IX, 3. Relation between structure of alloys and their electrical properties.
Broniewski. Thesis. Paris. 1911. Electrical properties of alloys of aluminum.
Ledoux. Comptes Rendus, 155 (1912), pp. 35, 1249. Electrical properties of Cu-Sn alloys. Electrical resistance shows a sharp cusp at Cu_4Sn and minimum at Cu_3Sn. Thermo-electric curve has minimum at Cu_4Sn and maximum at Cu_3Sn.
Pushin & Baskow. Jl. Russ. Phy. Chem. Soc., 45, 746. Electric conductivity of Cu-Sn alloys.
Pushin & Rjaschsky. Zeits. für anorgan. Chem., 82 (1913), 50. The Cu-Zn alloys.
Norsa. Comptes Rendus, 155 (1912), 348. Electrical properties of Cu-Zn alloys. Conductivity shows sharp cusp at CuZn and minimum about Cu_2Zn_3. The thermo-electric curve has additional cusp at $CuZn_2$.
Pushin & Dischler. Zeits. für anorgan. Chem., 80, 65. Electrical conductivity of Cu-As alloys.

Sieverts. Internat. Jl. Metallog., III, 37. Influence of dissolved gases on the electrical resistance of metal wires. Resistance of wires measured in vacuo and then in different gases.
Somerville. Physical Review, 30 (1910), 532; 31 (1910), 261. Temperature coefficients of electrical resistance. Data on various metals, such as manganin, constantin, "advance," "Ia-Ia" and on Ag, Al, Au, Cu, Fe, Mg, Mo, Ni, W.
Stepanow. Zeits für anorgan. Chem., 78 (1912), 1. Uber die elektrische Leitfahigkeit der Metallegierungen. Alloys of Mg with Bi, Cu, Pb, Sn, and Zn.
Beckman. Arkiv für Matematik Astronomie Fysik, (42) 7, (1912), 1. The influence of pressure on the electrical conductivity of alloys; Ag-Au, Au-Ni, Cd-Pb.
Grüneisen. Verhand Deutsch. Phys. Ges., 15 (1913), 186. The influence of temperature and pressure on the electrical resistanc of metals; Ag, Al, Au, etc., Ag-Au, Ir-Pt.

Magnetic Properties

The magnetic properties of Ni, Co, and Fe alloys have been studied by several investigators, notably by Guertler, Waehlert, and others already referred to under the binary alloys.

In 1903 Heussler prepared alloys of copper, manganese and aluminum and found them to be magnetic. The magnetism was explained by a ternary compound $Alx(MnCu_3x)_3x$. Ross put forward the theory that the alloys consist of solid solutions of the binary compounds Cu_3Al and Mn_3Al, but Rosenhain showed that alloys of aluminum and manganese alone are strongly magnetic.

Heusler Alloys

Heusler. Zeits. angewandte Chem., 25 (1912), 2253.
Heusler & Take. Trans. Faraday Society, VIII (1912) ,169.
Knowlton. Physical Review, 32 (1911), 54.
Knowlton & Clifford. Trans. Faraday Society, VIII (1912), 195.
Ross. Ibid, p. 185.
Take & Semm. Verhandl. Deutsch. Phys. Ges., 16 (1914), 971.

Various.

Eger. Internat. Jl. Metallogr., V (1914), 278. Neuere Fortschungen über den Magnetismus der Metalle and Legierungen.
Honda & Sone. Sci. Rep. Tohoku Univ., 2 (1913), 1. The magnetic susceptibility of binary alloys.
Leroux. Comptes Rendus, 156, 1764. Etude magnetique de la constitution de quelques alliages d'antimoine.
Weiss. Trans. Faraday Society, VIII (1912), 149. Magnetic properties of ferromagnetic metals; Co-Fe, Co-Ni, Fe-Ni.

6. Corrosion.

The corrosion of brass has been the subject of a great deal of research. Two causes have been assigned: First, when the alloys are composed of the constituents alpha and beta, there is a difference of potential between the two, the beta becomes the anode and is destroyed through the zinc going into solution, leaving a porous mass of copper behind. Second,

when the alloy consists of homogeneous alpha, a difference of potential may be set up by adherent impurities on the surface, or by strain, and corrosion begins through electrolysis. When once begun, the presence of metallic copper, which becomes the cathode to the alpha solid solution, hastens the corrosion materially and the brass is rapidly eaten through.

On the other hand, Bengough and Jones have maintained that the influence of the juxtaposition of two phases and the influence of deposits and particles are unimportant. They advocate the abandonment of the 70/30 brass for condenser tubes and the use of Admiralty mixture 70 Cu, 29 Zn, 1 Sn, or Muntz special brass 70 Cu, 28 Zn, 2 Pb. Control of temperature and electrochemical protection are advocated. Desch and Whyte found no evidence that the presence of tin gave less tendency to corrosion. The well-known protective influence is due to the adherent deposit formed. The presence of iron accelerates corrosion. Investigating the 70/30 alloy, they found, using alloys with 1% Sn, 1% Pb, and 2% Pb, the greatest corrosion with 1% Sn, the least with 2% Pb.

Bailey investigated the corrosion of aluminum. The presence of copper or sodium accelerates corrosion. Where the percentage of Si is greater that the percentage of Fe the action is less pronounced in water or acids but more pronounced in salt solution. Water and common salt solution free from air have no corrosive action.

Corrosion.

Bengough. Jl. Inst. Metals, V, 28. First report to corrosion committee. Review of previous work. Suggested experiments.

Bengough & Jones. Jl. Inst. Metals, X, 13. Second report. Corrosion of condenser tubes. 70/28/2; 61/39; and 70/29/1 brasses. Complete and selective corrosion (pitting). Control of temperature. Electrochemical protection.

Desch & Whyte. Jl. Inst. Metals, X, 304. "The microchemistry of corrosion I." Study of three alloys. 53/47, pure; 1.16% Sn; 1.05% Fe. Iron accelerates corrosion. No evidence in favor of Sn. A study of beta alloys.

Desch & Whyte. Jl. Inst. Metals, XI, 235. "The microchemistry of corrosion II." The alpha alloys of Cu and Zn. Four alloys: 70/30 pure; 1% Sn; 1% Pb; 2% Pb.

Whyte. Jl. Inst. Metals, March, 1915. "The microchemistry of corrosion III." The alpha and beta alloys of Cu and Zn. Five alloys, pure muntz, unannealed and annealed; 0.95% Fe; 1.09% Pb; 0.95% Sn.

Guertler. Internat. Jl. Metallog., II, 178. Der gegenwartige Stand des Korrosionsproblems.

Philip. Jl. Inst. Metals, VII, 50. Contributions to the theory of corrosion I. Corrosion of condenser tubes by contact with electronegative substances.

Phillip. Jl. Inst. Metals, IX, 61. Part II. Corrosion of distilling condenser tubes.

Phillip. Jl. Inst. Metals, XII, 133. Part III. Coke, condenser tubes, and corrosion.

Bruhl. Jl. Inst. Metals, VI, 279. Corrosion of brass. Study of corrosion of condenser-tube material. Fe, Ni and small amounts of Pb are bad. Tin to 1%, large amounts of Pb, and Al diminish corrosion.

Bassett. Jl. Indus. and Engineering Chem., IV (1912), 167. Need of special alloys for special purposes. Use of alloys under disintegrating conditions, condenser tubes, screens, etc.

Lyon. Engineer, 116 (1913), 451. "Corrosion and Preservation of Metals." Metals used in marine construction.

Vaughan. Trans. Amer. Brass Found. Assoc., V (1911). Corrosion of brass foundry products.

Giolitti & Cecarelli. Gazz. Chim. Ital., 39, 557. Corrosion of bronze. Relation between microstructure and rate of corrosion. 0 to 10% Sn. Presence of alpha and beta hastens corrosion. Nonhomogeneous alpha corrodes.

Bailey. Jl. Inst. Metals, IX, 79. Corrosion of aluminum. Corrosion increases with impurity. Presence of Cu or Na increases it. Annealing decreases it.

Guertler. Internat. Jl. Metallog., I, 353. Study of structure of galvanized irons. $FeZn_3$ more electro-negative than Fe or Zn. $FeZn_7$ also electro-negative to zinc, and hastens corrosion of zinc covering. Sheradized outer skins porous; also electro-galvanized.

7. New Applications of Metallographic Methods to Sulphides, Etc.

The binary alloys of the metal and its sulphide have been worked out in a great many cases, notably by Friedrich, Bornemann, and by Jaeger and Van Klooster. The binary alloys of two sulphides have also been studied extensively. The consitution of the series Cu_2S-FeS is still a bone of contention. Bornemann and Schreyer find four compounds, while Baykoff and Troutneff's curve shows a series of solid solutions with a minimum of 45% Cu_2S and 956°C. These differ markedly from the older results of Rontgen and of Hofman.

The binary alloys of the metal and arsenic have also been studied in a great many cases. Just as the Cu_2S-FeS series is important in the study of mattes, so is the Co-Ni-As series to the study of speisses. The system has been examined by Friedrich, who has determined the ternary freezing surface for Co-CoAs-NiAs-Ni.

The study of rock formation, slags, portland cement, etc., has led to much preliminary work along metallographic lines. The work of the Geo-Physical Laboratory, Washington, stands out in this line. The first six references are typical of their research. Shepherd and Rankin have given us the

ternary diagram for the CaO-Al_2O_3-SiO_2 series, with a study of portland cement clinker.

Lastly, the application of metallographic methods to the study of opaque ores is yielding valuable results. Along this line, two papers, those of Graton and Murdock, and of Singewald, need special attention, as indicating the results which can be obtained.

Sulphides.

Bissett. Trans. Chem. Soc. London, 105 (1914), 1223. The system of Ag-Ag_2S. Eutectic at 804°C. and 1% Ag. Two liquids at 903°C. have 14.25 and 94.25 Ag_2S. Ag_2S freezes at 815°C.

Bornemann. Metallurgie, VII, 667. Das system Nickel-Schwefel. Also Metallurgie, V, 13. Complex system.

Bucker. Stahl und Eisen, 32 (1912), 1017. The Fe-FeS system. FeS freezes at 1192°C. Eutectic at 84.8% FeS and 985°C. Thermal changes at 900°, 750°, 298°, and 138°C. No solid solutions formed.

Friedrich & Waehlert. Metall und Erz, X (1913), 976. The Cu-Cu_2S system. Two solutions at 1104°C. are 8 and 96% Cu_2S. (Similar work on Cu-Pb: Metall und Erz, X, 575.)

Jaeger & Van Klooster. Zeits. für anorgan. Chem., 78, 245. The systems Ag-Ag_2S; Sb-Sb_2S_3 are similar.

Bornemann & Schreyer. Metallurgie, VI, 619. The system Cu_2S-FeS shows four compounds.

Baykoff & Troutneff. Revue de Met., VI, 519. On the nature of copper mattes. Curve for FeS-Cu_2S shows a series of solid solutions with a minimum of 45% Cu_2S and 956°C. Cu-FeS diagrams.

Friedrich. Metall und Erz, XI, pp. 79, 160, 196. The system Na_2S-Na_2S_5 shows several compounds. Cu_2S-Ni_3S_2 forms a eutectic at 725°C. and 91% Ni_3S_2. Cu_2S-Ni_2S form one at 575° and 94% Ni_2S. The system Na_2S-Cu_2S shows a compound Na_4SCu_2S and two eutectics. The systems of Ni_3S_2 and Ni_2S with Na_2S both show two liquid solutions. like Cu-Cu_2S. The Orford process.

Hayward. Trans. Am. Inst. Min. Eng., 48 (1914), 141. System Cu_2S-Ni_3S_2. Eutectic at 727°C. and 23% Cu_2S.

Heike. Metallurgie, IX, 313. The PbS-SnS system forms a compound $PbSnS_2$, at 900°C., which forms a series of solid solutions with SnS, but is the groundmass of PbS.

Jaeger & Van Klooster. Verslagen Kon. Akademie. Wetens., Amsterdam, 20 (1911), 510. The system of PbS-Sb_2S_3.

Jaeger & Van Klooster. Verslagen Kon Akademie. idem p. 497. The systems Sb-Sb_2S_3: Ag-Ag_2S: Ag_2S-Sb_2S_3.

Jaeger. Eighth International Congress of Applied Chemistry, New York, Sept., 1912. Abs. Revue de Met., X (1913), 16. Sulphoantimonites and sulphoarsenites, natural and artificial. Ag_2S-Sb_2S_3 form two compounds, Ag_3SbS_3 and $Ag_3Sb_3S_4$ and three eutectics result. Ag_2S-As_2S_3 forms $3As_2S_3Ag_2S$ and $As_2S_3Ag_2S$ with two eutectics shown. The system PbS-Sb_2S_3 shows 2 $PbS.Sb_2S_3$ and 5 $PbS.4Sb_2S_3$ both by reaction. One eutectic.

Haan. Metall und Erz., X, 831. The system SnS-FeS forms a eutectic at 785°C. and 15% FeS. SnS melts at 870°C. and FeS at 1188°C.

Parravano & Cesaris. Gazz. Chim. Ital., 42, II, 1. The system Sb_2S_3-SnS. One compound, $SnS.Sb_2S_3$.

Parravano & Cesaris. Gazz. Chim. Ital., Ibid., p. 189. The system Cu_2S-Sb_2S_3. Two compounds: $CuSbS_2$ and Cu_3SbS_3.

Pelabon. Comptes Rendus, 156, 705. PbS-Sb_2S_3.

Schoen. Metallurgie, VIII, 737. The system Ag_2S-FeS shows a eutectic at 615°C. and 11% FeS.

Wagenmann. Metallurgie, IX, pp. 518, 537. The system PbS-Sb_2S_3

shows a compound, 2 PbS,Sb_2S_3, which forms the groundmass for PbS and a eutectic with Sb_2S_3 at 425°C. and 18% PbS. Laugprozess. $Pb_3Sb_2S_6 + 2\ Na_2S = Na_4Sb_2S_5 + 2\ PbS$.

Arsenides.

Dieckmann. Dissertation. Berlin (1911). Arsenides of iron, manganese and chrome. Chemical and magnetic properties.

Friedrich. Metall und Erz, X, 659. The system CoAs-NiAs. A series of solid solutions like NiCu. The ternary freezing surface determined for Co-Ni-NiAs-CoAs.

Heike. Internat. Jl. Metallog., VI (1914), 49. The system Pb-As shows a eutectic at 3.2% As and 280°C. No solid solutions.

Heike. Internat. Jl Metallog., VI, 209. The system Bi-As shows As crystallizing out in a groundmass of Bi. (like Bi-Cu.)

Parravano & Cesaris. Gazz. Chim. Ital., 42, 341. Internat. Jl. Metallog., II, 70. The Sb-As system worked out to 40% As. Shows solid solutions with minimum at 17.5% As and 612°C.

Parravano & Cesaris. Internat. Jl. Metallog., II, 1. The Sn-As system shows two compounds, SnAs, 61.3% Sn; Sn_3As_2, 70.4% Sn. Groundmass is pure tin.

Schemtschuschny. Internat. Jl. Metallog., IV, 228. The Cd-As system forms Cd_3As_2 at 721°C. and $CdAs_2$ at 621°C., which is suppressed by undercooling, as in Cd-Sb series. Eutectic of compounds at 610°C.

Schleicher. Internat. Jl. Metallog., VI, 18. The gold-arsenic system shows a eutectic at 665°C. and 25% As.

Schoen. Metallurgie, VIII, 737. Revue de Met., 1911, 739. The Mn-As diagram to 57% As shows Mn_2As at 1030° and MnAs at maxima. Therefore two eutectics, 22% As at 930°C., and 51% As at 870°C.

Silicates, Oxides, Etc.

Day & Shepherd. Jl. Amer. Chem. Soc., 28, Sept., 1906. Lime—silica diagram.

Allen & White. Amer. Jl. Science, 27, Jan., 1909. $CaSiO_3$-$MgSiO_3$.

Shepherd & Rankin. Amer. Jl. Science, Oct. 28, 1909. Al_2O_3 with SiO_2, CaO, and MgO diagrams.

Shepherd & Rankin. Jl. Indust. and Engineer. Chem., III, April, 1911. The ternary system CaO-Al_2O_3-SiO_2.

Rankin. Amer. Jl. Science, 39, Jan., 1915, pp. 1-79. The ternary system, CaO-Al_2O_3-SiO_2.

Anderson. Amer. Jl. Science, 39, April, 1915, 407. The system Anorthite-Forsterite-Silica.

Ginsberg. Zeits. für anorgan. Chem., 59, 346. The system $CaSiO_3$-$MnSiO_3$. A series of solid solutions with a minimum at 12.8% $CaSiO_3$ and 1184°C. Rooseboom's type 3.

Lebedow. Zeits für anorgan. Chem., 70, 301. The systems $MgSiO_3$-$MnSiO_3$; $CaSiO_3$-$BaSiO_3$; and CaSiO3-CaS. The first belongs to Rooseboom's type 4. Reaction at 1325°C. The second is type 3. Minimum at 1000°C. and 66% $CaSiO_3$. The third, up to 50% CaS, a series of solid solutions.

Klooster. Zeits für anorgan. Chem., 69, 135. The system SiO_2-Li_2SiO_3-Li_4SiO_4 has two eutectics. The system Li_2SiO_3-$ZnSiO_3$ forms a eutectic at 50% and 1000°C. (?), while $ZnSiO_3$-$CaSiO_3$ belong to type 3 with a minimum at 1052°C. and 30% $ZnSiO_3$. The system Li_2SiO_3-$LiBO_2$ has eutectic at 800°C. and 28% Li_2SiO_3. Also Na_2SiO_3-$NaBO_2$ forms a eutectic at 815°C. and 55% Na_2SiO_3, while Na_2SiO_3-Na_2WO_4 is a case of partial solidity like Pb-Cu.

Wallace. Zeits. für anorgan. Chem., 63, 1. Na_2SiO_3 and $CaSiO_3$ forms a compound: $2Na_2SiO_3$, $3CaSiO_3$ at 1175°C. The diagram shows a minimum (type 3) at 932° and 20% $CaSiO_3$ between the compound and Na_2SiO_3, and a eutectic with $CaSiO_3$ at 1140°C. and 69% $CaSiO_3$. The system Na_2SiO_3-$SrSiO_3$, minimum at 875°C. and 20% $SrSiO_3$, is type 3; similarly Na_2SiO_3-$BaSiO_3$ and Na_2SiO_3-$LiSiO_3$. To type 5, eu-

tectiferous, belong $CaSiO_3$-Li_2SiO_3; $MgSiO_3$-Li_2SiO_3; $BaSiO_3$-Li_2SiO_3; and Li_2SiO_3-$SrSiO_3$. The ternary diagram Al_2O_3-SiO_2-Na_2O is given in part.

Karendeeff. Zeits für anorgan. Chem., 68, 188. The $CaSiO_3$-CaF_2 system shows eutectic at 1130°C. and 38% CaF_2; while $CaSiO_3$-$CaCl_2$ resembles the Cu-Bi curve.

Colony. "Petrographic Study of Portland Cement." Sch. Mines Quart., Nov., 1914. Reactions that occur during sintering, slaking, setting, and hardening of portland cement.

Doerinckel. Metallurgie, VIII (1911), 201. The system MnO-SiO_2 shows two compounds: $2MnOSiO_2$ and $MnOSiO_2$, both formed by reaction. They form a eutectic at 1170°C. and 41% SiO_2.

Hilpert & Nacken. Metallurgie, VIII, 157. The PbO and $PbSiO_3$ diagram shows two maxima, Pb_2SiO_4 at 740°C., and 3PbO2SiO2 at 700°C., and three eutectics.

Nielson. Ferrum, X, 97. Study of the system CaO-P_2O_5-SiO_2. One compound, $3CaO,P_2O_5$, $3SiO_2$. Melting-point, 1630°C.

Van Eyk. Zeits. für physik. Chem., 30, 430. $TlNO_3$-KNO_3. Typical eutectoids.

Van Eyk. Zeits. für physik. Chem., 51, 731. $TlNO_3$-$AgNO_3$ and $TlNO_3$-$NaNO_3$.

Plato. Zeits. für physik. Chem., 58, 530. Erstarrungs-erscheinungen aus anorganischen Salzen. $SrCl_2$-SrF_2; $BaCl_2$-BaF_2;$CaCl_2$-CaF_2; Na-Cl-NaF; KCl-KF.

Parravano & Calcagni. Zeits. für anorgan. Chem., 65, 1. The systems KPO_3-$K_4P_2O_7$, and $NaPO_3$-$Na_4P_2O_7$, both eutectiferous.

Klooster. Zeits. für anorgan. Chem., 69, 122. Diagrams for KPO_3-KBO_2; $NaBO_2$-KBO_2; and $LiBO_2$-$NaBO_2$. The first forms a compound KPO_3KBO_2 at 885°C., with two eutectics; the second is type 3, minimum at 850° & 50%; the third is eutectiferous, 640°C. and 50%.

Fedotieff & Iljinski. Zeits. für anorgan. Chem., 80 (1913), 113. NaF and AlF_3 system. Compounds 3 $NaFAlF_3$ at maximum, 1000°C., and 5 $NaF,3AlF_3$ by reaction. Eutectics 885°C. and 14%; 685° and 46 mol % AlF_3. The system Al_2O_3-$3NaF,AlF_3$ studied in part. "Contribution to the study of electrometallurgy of aluminum."

Kohlmeyer. Metall und Erz, X, pp. 447, 483. "Uber Blei-oxid und Eisenoxydulferrite." The systems PbO-Fe_2O_3 and FeO-Fe_2O_3 show several compounds formed by reaction.

Kohlmeyer & Hilpert. Metallurgie, VII, 225. Uber Calciumferrite. The diagram CaO-Fe_2O_3 shows four compounds, 3CaO, $2Fe_2O_3$, and 2CaO3-Fe_2O_3 occurring at maxima. Three eutectics, the lowest at 1200°C. and 50 mol. %.

Truthe. Zeits. für anorgan. Chem., 75 (1912), 129. The systems AgCN-KCN; AgCN-NaCN; $Cu_2(CN)_2$-KCN, and $Cu(CN)_2$-NaCN. Compounds formed in each case.

Truthe. Zeits. für anorgan. Chem., 76, 161. The systems PbS-$PbCl_2$; Cu_2S-$CuCl_2$; Ag_2S-AgCl, all show eutectics, while Cu_2O-Cu_2Cl_2 resembles the Bi-Cu type.

Microscopic Examination of Opaque Ore

Campbell. Economic Geology, I, 751. The Microscopic Examination of Opaque Minerals.

Campbell & Knight. Economic Geology, II, 350. Nickelferous Pyrrohtites.

Campbell & Knight. Economic Geology, I, 767. Cobalt-Nickel Arsenides of Temiskaming.

Boyle. Trans. Am. Inst. Min. Eng., 48 (1914), 97. Ore deposits of Bully Hill District, Cal.

Bruce. Sch. Mines Quart., 35 (1914), 187. Microscopic Tests of Opaque Minerals.

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8. Recent Literature.

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Now we have Guertler's Textbook of Metallography Vol. I and II; Desch's "Metallography"; Gulliver's "Metallic Alloys"; Rosenhain's "Introduction to Physical Metallurgy", and a number of smaller works. Some of the more recent are given below. As a starting point, to find the literature on any subject, the abstracts in the International Journal of Metallography, and in the Journal of the Institute of Metals, London, cover the field exceedingly well.

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Smith. "Sir William Roberts-Austen. A record of his work." 1914. Griffin.
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ALUMNI NOTES.

1883. Walter Harvey Weed, E.M., visited Newfoundland in August, to examine a mining property on Notre Dame Bay.

1900. H. T. Dickinson, E.M., assistant general manager of the DeBeers Consolidated Mines, Kimberly, So. Africa, is expected in San Francisco about Oct. 1. Address while in the United States, Columbia Club, New York City.

1902. A. L. Queneau, E.M., who has been with the English engineers engaged in the European war, and was nearly a victim of German gas at the battle of Ypres, has received decorations from both English and French generals, for distinguished service.

1903. H. C. Wilmot, E.M., has returned from the Philippine Islands, and is now at Baker, Ore.

1907. Jesse J. MacDonald is engaged in the oil flotation department of the Ray Consolidated Copper Co., at Hayden, Ariz.

1910. Homer L. Carr, E.M., has been appointed Instructor in Mining at the Columbia School of Mines. During August, 1915, he was engaged in place-prospecting in Ontario, Canada.

1910. R. A. McGovern, E.M., who is engaged in the installation of oil-burning steam plants at Rio de Janiero, Brazil, spent a few days in New York in August, 1915.

1910. M. B. Evans, E.M., who for the past three years has been mine engineer and more recently mill superintendent for the Javali Mining Co., at La Libertad, Chontales, Nicaraugua, returned to New York in July, 1915.

1910. H. C. Carlisle, E.M., was engaged by Tonopah capitalists to examine the Panama Mining Company's property on the east coast of Nicaragua, early in 1915.

1911. E. H. Dickenson, E.M., formerly superintendent of the Midas mine, near Valdez, Alaska, and for the past year engaged in the installation of a high-voltage transmission line in Quebec, visited New York in September, 1915. Permanent address, 19 W. 91st St., New York.

1911. L. M. Thompson, E.M., and J. M. Hoffman, E.M., are on the staff of the Cie. Forminière, at Tshikapa, district of Kasai, Belgian Congo, West Africa. Thompson paid a visit to New York in October, 1915.

1911. W. R. Wright, E.M., is connected with the firm of W. & W. F. Crockett, building contractors, 306 E. 59th St., New York.

1911. Clark G. Mitchell, E.M., is superintendent of the Isabella mine, at Cripple Creek, Colo.

1911. W. L. Thomas, E.M., is consulting mining engineer with the banking firm Moore & Schley, New York. In the fall of 1915, he was engaged in examination of mineral properties at Porcupine, Ontario.

1912. R. A. Semple, E.M., until recently manager of the Easton mine, Virginia City, Montana, returned to New York in September, 1915.

1912. C. T. Carney, E.M., who is engineer for a 1000-ton per day coal mine near Des Moines, Iowa, visited New York for a few days in September, 1915.

1912. J. L. Claghorn, E.M., with a number of associates, is engaged in reopening an old gold mine near the North Star, in Grass Valley, Cal. He paid a short visit to New York in September, 1915.

1912. C. B. Whitwell, E.M., has an office as engineer and assayer at Grass Valley, Cal.

1913. Ned E. Nelson, E.M., of Phoenix, B. C., announces the birth of a daughter, Emily Louise, on July 28, 1915.

1913. Albert H. Israel, Mech. E., since March, 1915, has been superintendent of tests and erection for the Terry Steam Turbine Co., of Hartford, Conn.

Stockholders in the New Jersey Zinc Co. will be gratified to know that the technical management of the company's mines is in good hands. George C. Stone, '79, formerly chief engineer, is now President of the company. Benjamin F. Tillson, '07, is engineer of both mines at Franklin, N. J.; C. M. Haight, '06, and H. H. Hodgkinson, '10, are engineers of the Taylor and the Parker mines, respectively; J. Cornellisen, '14, and G. S. Patterson, '14, are shift bosses in the two mines; and H. Brandenburg, '15, and S. Margon, '15, are now working as timberman and drill runner.

1913. Roy S. Bonsib, E.M., is assistant engineer with the Low Moor Iron Co., at Low Moor, Va.

1915. J. A. Thomas, E.M., is superintendent of the Aetna Chemical Company's works at Drummondville, Quebec. Head office of the company is 2 Rector St., New York.

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THE

SCHOOL OF MINES QUARTERLY.

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THE
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VOL. XXXVI. JULY, 1915. No. 4.

RETIREMENT OF PROF. HENRY S. MUNROE*

On May 28, at the Chemists' Club, New York, a testimonial dinner was given to Henry Smith Munroe, Professor of Mining in Columbia University, from 1877 to 1915. The dinner was given under the auspices of the Alumni Association of the School of Mines, its special occasion being the approaching retirement of Professor Munroe, which was to occur coincidently with the close of the collegiate year. Professor Munroe, who was the senior member of the faculty, had completed 38 years of service.

The dinner was arranged by a committee of which George C. Stone, '79, was chairman. Over 100 attended. The speaking following the dinner was begun by R. V. Norris, President of the Alumni Association, who introduced Prof. J. F. Kemp as toastmaster. The other speakers were Nicholas Murray Butler for the University; Thomas Haight Leggett for the American Institute of Mining Engineers; Walter Renton Ingalls for the Mining and Metallurgical Society of America; and John Parke Channing for the Alumni. In concluding his remarks Mr. Channing gracefully presented to Professor Munroe, on behalf of the former students of the latter, a massive bronze—The Sluice-Miner—by Louis Potter.

R. V. Norris.—It is a privilege to be able to join with you tonight in honoring the senior professor of Columbia. In the days of 49th Street, when the College occupied a maison of which the less said the better, and was an appendage to the School of Mines, Professor Munroe, a young and enthusiastic

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man, taught most of us the principles of mining. It was my good fortune to be his assistant in the summer school of 1885 and to learn to appreciate fully his character and attainments. I remember once discussing Professor Munroe's title with him, a title for which he claimed special honor and distinction. The title of "Professor," he insisted, was assumed by charlatans, corn-doctors, barbers, etc., while he and Hutton were the only simon-pure "Adjunct Professors" in existence.

We all recognize and appreciate Professor Munroe's services to the School, and still more to ourselves, and feel a great loss in the severing of his long and useful connection with Columbia. When the College was removed to its present site, the older Alumni were horrified and exasperated to find that our School of Mines had disappeared and was merely an item in a "School of Science", a clear case of the tail attempting to wag the dog. For a few years Professors Munroe and Peele were practically the Mines; then, most fortunately, Mr. Lewisohn sensed the situation and gave us back our old School of Mines.

I have always found that geologists were better talkers than the miners, and it gives me great pleasure to introduce to you one of Professor Munroe's assistants in the summer school of 1885, our toastmaster, Professor Kemp.

Professor Kemp.—Last May we celebrated the fiftieth anniversary of the School. Tonight we celebrate the thirty-eighth anniversary of another institution, because Professor Munroe has been so long and so influentially connected with the School of Mines, that he has become an institution in himself. We cannot think of these thirty-eight years without running back in our minds to the old days at the 49th Street site. We pass again through the gate, across the yard and up the steps through the door beneath the semicircular sign "School of Mines." We avoid the door on the left, which leads to the room where George F. Fisher and Bobby Ricketts used to hand out tuition bills and library books with equal impartiality, and where Dr. Chandler gave sick-excuses to the varsity crew and similar invalids. On the right we avoid the door into the qualitative laboratory, always an inferno of vile smells and acid vapors. Up the winding stairs we go, on our way to the lecture room of Professor Munroe, and on the

PROFESSOR HENRY SMITH MUNROE.

second floor we pass the door on one side, behind which Professor Egleston was wont to describe the furnace of Tubal Cain and the Agordo process of extracting copper from its ores, even if it had not been used in forty years. On the other side we dodge the entrance to the quantitative laboratory where President Barnard used to catch Dr. Waller smoking a cigarette about three times each week, to the anarchial destruction of all the University's rules and regulations. Up another flight of stairs we climb and enter the first door on the right.

Now, as to what transpired in Professor Munroe's lecture room, I know no better way to remind you than to quote one of the lesser poets who once tried to describe it in the flowing Wurzburger meter:

> With sound mathematics, with calculus, trig,
> He taught us for ore in the mountains to dig,
> To crush with a stamp, and to wash on a jig,
> Down in the Old School of Mines.

But Professor Munroe was not satisfied with the lecture room alone. As far back as the summer of 1877 he took the class of '78 to the collieries of the late Eckley B. Coxe, to spend some weeks in actual underground experience and study. The next summer the class of '79 was taken to Mineville near Port Henry; the annual pilgrimages then became well established and have since been continued in all parts of the country. In this step, Professor Munroe grasped at once a solution for one of the serious problems of technical education.

Mining, however, was not the only subject falling to him to teach. Surveying also fell to his lot. My own classes were taught to pace over "rough and uneven ground," lay out farms and build imaginary railways among the squatter shanties which then occupied the present site of the beautiful Morningside Park. The Professor made one serious error. He established headquarters and storage for the levels and transits in the beer garden of the Lion Brewery at Columbus Ave. and 108th St. The necessary and frequent visits to this resort started on their downward careers, toward their present condition, those members of '84 whom you see at the table at my left. When Professor Munroe realized this baleful result, he felt the imperative need of a summer camp and finally se-

cured the site of Camp Columbia, near Litchfield, Connecticut, the only site within 150 miles of New York which is at the same time four miles from the nearest glass of beer. As to what is done at Camp Columbia we may learn if we call again upon the lesser known poet of the Wurzburger meter:

> With transit and level; with axe and stake,
> They teach us elaborate surveys to make,
> And to see if a bottom holds up Bantam Lake,
> Down at the Old School of Mines.

These changes, and many others in the line of improvement, we owe to Professor Munroe. His old students have felt that they simply must have him as their guest tonight and must tell him of the debt which they owe him.

We are proud and honored to have with us the President of the University, and I have the great pleasure of presenting to you, as the first speaker, one who combines in a singularly happy degree the farsighted vision of the scholar with the efficiency of a captain of industry, Dr. Butler.

President Butler paid glowing tribute to the energy and devotion with which Professor Munroe had maintained the ideals of the School of Mines for nearly forty years. Graduating with one of its earliest classes, Professor Munroe returned after several years of travel and professional work to lecture on mining and ore-dressing, and for a long time shared with Egleston, Trowbridge, Van Amringe, and others of the original faculty, the onerous duties and also the pleasures connected with the growth of the school in efficiency and prestige. Professor Munroe never wavered from the high ideals adopted at the outset by the founders of the school, and consistently adhered to the high standards set by them, standards to which some other parts of the present University have attained only within comparatively recent years. As senior professor of the faculty, the whole University thus owes him the deepest gratitude for his consistent upholding of its traditions.

President Butler next mentioned more specifically a noteworthy feature of the present work of the University which had its origin in Professor Munroe's farsightedness—the Summer School. The first summer school ever organized in Columbia was that which Professor Munroe conducted at Drifton, in 1877, for the study of practical mining. That

branch of study has been maintained without interruption to the present day, and from it have grown the important practical studies along parallel lines now conducted every summer at Camp Columbia; but more impressive still is the present magnitude of the educational work at the University itself, enrolling thousands of students for six weeks every summer, all of which is the direct outgrowth of Professor Munroe's farsighted vision.

In retiring from his active duties as an educator, Professor Munroe, so President Butler explained, would now enjoy more ample opportunity to conduct experiments and research towards the solution of certain mining problems. The mine leased by the University at Roxbury, Conn., has been placed at his disposal, with sufficient funds, due largely to the generosity of Dr. James Douglas, to supply equipment needed for the proposed experiments. The engineering profession, and the University in particular, will wait with confidence for the valuable results expected from these tests.

In conclusion, President Butler spoke with deep feeling of his personal regret at the loss of association with Professor Munroe; of the Professor's unfailing courtesy, of his gentlemanly consideration for others; and of his untiring devotion to the welfare of the School of Mines.

(Owing to the failure to secure a verbatim report of President Butler's address, and to his inability at this time to prepare a written memorandum, the preceding paragraphs, based on the recollection of some who were present at the dinner, are inserted as a substantially correct report of what Dr. Butler said.—Ed.)

Professor Kemp.—We are rejoiced to have as the representative of American Institute of Mining Engineers, of which Professor Munroe has been a member for 43 years, one of its vice-presidents, Mr. Thomas H. Leggett.

Mr. Leggett.—My lines tonight have certainly fallen in pleasant places, since in speaking, as I have been asked to do, for the American Institute of Mining Engineers, in acknowledgment of the debt which that Society owes to Professor Munroe, I can act in a dual capacity, having been an associate of Professor Munroe in the Society since 1882 and having also had the honor of studying under and being instructed by him

at the School of Mines in the late seventies. At the same time I admit the dangers of the position, for once a School of Mines man always a School of Mines man, you know, and I acknowledge and fear the tendency to let the School of Mines swamp the American Institute. This being in the family, and no reporters present, I can make this confession with less shamefacedness than I otherwise might as an officer of the American Institute. I must tell you, in confidence, that I belong to that "distinguished" Class of '79, of which Prof. Munroe flunked practically every blooming aspirant for the mining degree in the final examinations; and I can tell you that the old brick building was full of fellows running around like chickens with their heads cut off, wondering how they were going to get their coveted parchments on Commencement Day.

It may be as well to explain that the aforesaid class contained a group called the praying gang (not spelt with an "e," though perhaps it might have been) and their invocations sometimes interfered more or less with the proper atmosphere of attention and decorum in the various lecture rooms. Anyway, I am certain we all richly deserved our low marks; but in spite of this Professor Munroe kindly reconsidered the matter (of course, after a proper interval, duly filled with the right amount of anguish and repentance) and gave us the coveted passing mark of six. I am satisfied he did this not merely out of kindness of heart and consideration for us, although these undoubtedly were most important factors in his decision, but I have long felt that the chief reason for his permitting this escape from our just deserts was the farsighted vision with which Prof. Munroe is blessed. He could not bear so to cripple the mineral resources of this, and perhaps a few other countries, by refusing the stalwart aid of the shining marks of the Class of '79—so he let us through, "God bless him." In doing so he taught us a lesson not learned in text books, a lesson which was gratefully received—perhaps not gratefully received just at that moment, but after the lapse of time and looking at it through what the darkey preacher called the "Dim Futurity of the Past," it certainly is now gratefully received by all the flunked—and I, for one, am glad of this opportunity to express my sense of obligation to him for that lesson in particular.

Professor Munroe has been a trail blazer, a pioneer of the profession. T. A. Rickard told us "trade may follow the flag, but the flag follows the pick," and he proved his statement. Similarly, the mining course at the School of Mines has followed the lead of Prof. Munroe to its present high state of development and efficiency. Among other things he, as already pointed out by President Butler, started the first successful summer mining classes for practical work at the mines; they were soundly practical and, in my judgment, of inestimable value to the students. He took our class to the Witherbee iron mines at Port Henry, Lake Champlain, and I remember one of the first things he told me to do was to get into the skip and go down into one of the mines to see them packing a pump. The mine was an open pit four or five hundred feet wide and about three hundred feet deep (though it looked like three thousand to me), and as I took my first journey underground I distinctly remember seeing in my mind's eye a group of carpenters with packing boxes, excelsior and other things useful for packing a pump. Needless to say, I found it was not that kind of packing that was being done. From one practical thing we were led on to others, such as sharpening and tempering drill steel in the blacksmith shop, drilling holes underground and incidentally smashing an occasional finger, making notes on the mining methods, and finally to the more scientific work of mine surveying, dip-needle surveying, pumping, hoisting, and ventilating problems.

But I am forgetting the American Institute, of which Prof. Munroe was one of the very earliest members. He joined the Institute in 1872, was elected a manager (now termed Director) in 1881, and served as such till 1884, while in 1890 and '91 he was one of its vice-presidents. He has also served on various committees, notably those on mining and milling methods and on papers and publications. The Transactions of the Institute, of which there are now nearly fifty volumes, bear witness to his intellectual activity, his contributions in the way of papers and discussions being spread through the various volumes from No. V in 1876 up to the present time.

I have already alluded to the pioneer work that Prof. Munroe has done in the School of Mines, and I want to tell you that this is quite as forcibly illustrated in his contributions to

the American Institute. He has been a true pioneer in this, our chosen profession of mining engineering, and I will give chapter and verse in support of this statement and of the faith that is in me. Away back in 1880 he wrote a paper for the Institute on the "Weight, Fall and Speed of Stamps" in which he demonstrated conclusively that to increase the crushing effect of a battery it is better and more economical to increase the weight of the stamp than the height of the drop; he showed that all the advantage lay in heavy stamps and low drop, that 8 inches was the economical limit of height of drop, and that the stamp mill was a most inefficient fine-crushing machine. It was about the year 1900, or 20 years after Professor Munroe told the profession what to do, that operators even began to do it—and what have we today? We are using a 2000-pound stamp in place of one weighing 900 or 1000 pounds, we find the universal adoption of an 8-inch drop, and finally, as coarse crushing as possible, all the fine crushing being done outside the stamp battery by other machines, such as tube and Chilean mills.

Again, in 1880, Professor Munroe wrote an exhaustive paper on the "Losses in Copper Dressing at Lake Superior," in which he pointed out the high losses occurring in the concentrating mills, the reasons therefor, and the imperative necessity for finer grinding—and what do we see today? Only within the past two years these very tailings are being recovered from the lakes where they were deposited 20 or 30 years ago, and a large plant is being erected to reconcentrate them, the basic principle of which is finer grinding.

In 1888 he enriched the Transactions of the Institute with a masterly treatise on "The English versus the Continental System of Jigging," and I rightfully refer to it as a masterly work, for it contains more higher mathematics than, I am free to confess, I could digest in a month. I am not so ashamed to confess this as I might be, since I once asked a no less personage than the chief engineer of one of our biggest railroads how much he used calculus and the higher mathematics, and he replied, "Just as little as I can, and then I have a man in the outer office who does it for me." Withal, the higher mathematics are most useful, as shown by the eminently practical conclusions arrived at through their means by Professor Munroe; but I am not going to weary you with details

nor attempt to give you more than a cursory glance over the wide field of work he has covered.

I have said enough to show that his indefatigable and original researches and investigations have indeed blazed the trail for us to follow, and he did this years before our courage was equal to the task of following in his lead. It is difficult to say, therefore, to what heights of successful accomplishment he might not have risen had he chosen the work-a-day field of endeavor, instead of the higher sphere of usefulness that he has filled with such consummate ability for so many years.

I voice the feeling and the sentiments of the President, the officers, and the thousands of members of the American Institute of Mining Engineers in expressing to Professor Munroe our hearty appreciation of the invaluable services he has rendered the Institute, and our deep sense of the heavy debt and obligation his far-seeing work has laid upon, not only the American Institute, but the entire profession of mining engineers, and we wish for him, many, many more years, sure to be of increasing usefulness and enjoyment.

I used to be somewhat sympathetic with a man in Professor Munroe's present position, who has to sit still and hear the truth told about him without answering back, but I am losing that attitude; for when a man shows such intellectual force and vigor, such marked superiority over us "common or garden" run-of-mine engineers, let him suffer for his virtues and abilities; let him I say, while we talk about him, sit and wriggle with that sense of, shall I say, pleasing uneasiness. My sympathy, our sympathy for him is dead; but our appreciation, our esteem, our affection for him, these never die.

Professor Kemp.—The Mining and Metallurgical Society of America meets a widely felt desire for a society of restricted membership, for which is prescribed the qualification of years of successful professional service. In its organization Professor Munroe took a prominent part. He has served as councillor, as secretary, and as president, and has made frequent and valuable contributions to its discussions. The Society is represented tonight by its President, Walter R. Ingalls. In Mr. Ingalls we welcome also a graduate of our sister

we reached the street, "what do you mean by giving the engineering school, the Massachusetts Institute of Technology, founded at almost the same time as the School of Mines, and with closely similar ideals. Mr. Ingalls is also, I hardly need remind you, the ruling spirit of the Engineering and Mining Journal, a paper which possibly all here read with more regularity than we do our Bibles. In his hands the Journal has advanced in usefulness even above the high standard set bv its former and renowned editors.

Mr. Ingalls.—Whenever I am going to speak upon an occasion of this kind, the toastmaster always upsets my carefully arranged thoughts by saying things that should have been left unsaid. Here is Professor Kemp putting a coat on me that I feel does not, in all respects, belong to me. I ought to hand it back to him and ask if he has not made some mistake. Yet it is a nice coat, I like it, and perhaps if I do not say too much about it I may get away with it. I am like a man with whom I went to a barber shop one day last winter. After being broomed and whisked in the usual manner by the darkey attendant, on leaving he handed the fellow a dollar bill and hurriedly walked out. "Great Scott, man," I said to him when whiskbroom boy a dollar tip? Don't you know that was frightfully extravagant and contrary to all rules?" "Oh, yes," said he, "I know it was a munificent tip, but just look at the overcoat he gave me."

In making the preliminary arrangements with our genial toastmaster, our conversation, as usual, touched upon the length of time he thought it appropriate for me to address you. "Well," said he, "of course you may talk as long as you like, having due consideration for the probability that the guests will want to go home before morning." Nevertheless, a little piece of advice that is attributed to President Hadley of Yale, just occurs to me. President Hadley was going to preside at a meeting at which the principal speaker was to be a noted revivalist, (not, however, Billy Sunday); and the saviour of souls made a similar inquiry of him. Hadley replied, "Talk just as long as you like, Sir," but he added, "we have an idea, however—here in New Haven—that no sinners are ever saved after the first 20 minutes."

It may have been injudicious of me, nay, even inappropri-

ate, to tell a Yale story at a Columbia meeting. If so, I crave your forgiveness, and in extenuation of my impropriety let me plead that Professor Munroe has been a teacher not only of Columbia men, but also of mining engineers in general, including those of Yale, Harvard, Technology, and even of the Antipodes. He belongs not merely to Columbia, but to the profession at large; and for his writings, criticisms, and instructions, the world is his debtor. Seldom have we had a teacher so thorough, so conscientious, so careful. Let me cite an instance of one of the many occasions when I have sat with him and thankfully learned from him.

Some years ago there was held an exhibition of safety devices, including safety devices for mining, and somebody gave a gold medal to be awarded to the most meritorious device promoting safety in mining. The committee to award this medal was Professor Munroe, and a distinguished engineer whose name I have forgotten and will therefore refer to as Robinson, and myself. The exhibition comprised a variety of interesting and ingenious things, ranging from folding rowboats, for use in marine disasters, to proposed means for crossing Fifth Avenue and escaping being run over by automobiles. However, not much was offered in the mining line. Our committee became quite discouraged as to what to do with that gold medal. The management of the exhibition, being desirous of giving all possible eclat to their show, urged us to give it to somebody. Yet we did not want to give it to anybody who did not deserve it. Finally, Robinson said that a certain device for thawing frozen dynamite with perfect safety, it was claimed, seemed to him to be the best thing there; and indeed it looked pretty good. It was not in fact a dynamite-thawing apparatus, but my story is rather personal, wherefore it is advisable to disguise some of its features.

"Well," said Robinson, "I think we'd best give the medal to the dynamite thawer."

"Yes," said I, "let's do it."

Then up spoke Professor Munroe, who had theretofore been silent. "I'm doubtful about the wisdom of what you want to do," said he. "There is lurking in my mind the idea that I have heard this thing is not so good as it looks. Suppose we put the matter over until tomorrow afternoon."

Of course, Robinson and I gladly agreed to the suggestion.

The next afternoon Professor Munroe met us with the statement that he had spent the previous evening and the following morning looking up references in all kinds of French, British, German, and American reports, and that it was quite clear that the ingenious dynamite-thawer, which interested us and looked so good, had resulted in the loss of more lives than it had saved; and he submitted evidence, exhibiting his amazing erudition, that clinched the statement. Naturally we did not want to award the medal to such a dangerous thing, and there being no one else to whom we could reasonably give it, we returned it to the donor with the report that he would have to keep it for another year.

Subsequently we learned that the dynamite-thawing company felt hurt at our action. It never knew how near it came to receiving the medal.

Perhaps I ought not to have told this story, and would not have done so if I had been less immodest, for without any doubt it is one on me; and my lingering mortification is tempered only by the thought that Robinson was as deficient in discernment and knowledge as was I. But Professor Munroe saved the day for us; and I think that this illustration of his broad knowledge of the profession he has practiced and taught, of his conscientious carefulness, and the profoundness of his thinking, gives a better idea of the man than if I merely recited his many virtues to the full limit that Professor Kemp so gracefully suggested to me as that which it would be unwise to overstep.

Professor Kemp.—A few evenings since, in reading a small volume called "Pagan Poems" by our colleague, Professor Franklin H. Giddings, I came across these stanzas:

We know not why our life,
  Our smilings and our tears,
Why Nature's power works grimly on,
  Through the eternal years.

Yet dour or glad we strive,
  Loth from our task to cease,
Content if thus we learn to tell
  The blue-bird from the geese.

Among the many students who have passed under Professor Munroe's instruction, there is no one who has devel-

oped a finer or more discriminating sense of the difference, in matters connected with mining—"to tell the blue-bird from the geese"—than John Parke Channing, '83, who will speak for the alumni.

Mr. Channing.—Professor Munroe's personality was first impressed upon me in the summer of 1882, when our class went on its mining trip to Pennsylvania and New Jersey. As he led us down the slope of one of Eckley B. Coxe's coal mines at Drifton the expression "facilis descensus Averni" came to me, and, as it was my first visit underground, the difference between a mine and Hades was not very clear.

The summer was undoubtedly an important time in Professor Munroe's life, for we well remember seeing him collect large bunches of mountain laurel which were sent away to a mysterious destination, and on certain Fridays he, himself, would disappear and not return until Monday. His summer schooling resulted in his marriage to the lady whom we see beaming proudly upon him from the gallery.

In 1895 I was an assistant at the summer school mining trip to Colorado, through the invitation of Prof. Peele, and this trip remotely was the cause of my getting hold of the Miami property eleven years later, for at that time I first met Mr. F. C. Alsdorf in Central City, Colorado, who, in 1906, brought the property to my attention. Central City was then the home of a great many Cornishmen and my stock of Cornish stories was largely garnered from that field. Probably the most interesting one, on account of its local color, was the story of the Cornishman who came running down the trail from Central City to Black Hawk to catch a train for Denver. This was at the time when the railroad had not been extended to Central City. As he reached the platform, blowing hard, the train had just pulled out. Shaking his fist at it he cried, "Gose on, thee puffin Billy, damme I walked before thee was thought of."

We are all indebted to Professor Munroe, and I perhaps more than anyone else, for my position after graduation was secured by him in the Lake Superior mining district.

Professor Munroe, we regret that the School of Mines is losing your services, but we hope that it may have you in an advisory capacity so that you may give coming graduates

that matured advice which you have given so freely to us in the past. As an appreciation of our love and esteem for you, on behalf of the Alumni, I take pleasure in presenting to you this bronze by the late Louis Potter, modeled by him in Alaska, and known as "The Sluice Miner." In a way it exemplifies both mining and concentrating. Accept it please with our best wishes for your health and happiness.

Professor Munroe, in acknowledgement of the testimonial to him, delivered a scholarly address which was received with warm appreciation by those at the dinner, who considered that it revealed Professor Munroe to a depth that had not previously been perceived even by his oldest and most intimate students.

Professor Munroe.—A wise man once said, "An ounce of taffy is worth a pound of epitaffy." I suppose that I shall have to do without the epitaffy. I feel a little as if I were attending my own funeral feast. A year ago I came very near to being the subject for a funeral discourse, but, thanks to Heaven and the doctors, I am very much alive tonight and able to hear and enjoy the very flattering things that have been said about my work.

It is not easy for a modest man to stand so much eulogy, so many obituaries, as I have heard tonight, and it is not easy for a diffident man to reply to such praise or to acknowledge it as it deserves, especially if one is embarrassed by the knowledge that the picture is overdrawn, that one has not really earned quite so much credit. It woud be strange indeed, and I should be ashamed of myself, if in 38 years I had done nothing out of the ordinary. I am proud of my modest contributions to the reputation and influence of the School of Mines of this great University. I have enjoyed the working out of new ideas in the education of mining engineers. It has been a great pleasure to contribute to the usefulness of the School of Mines and to the efficiency of its graduates.

I am, however, quite conscious that I have left undone some things that I ought to have done; and have done sometimes, what I ought not to have done. Perhaps I may be able to do some of these things left undone in the future. But one often makes good resolutions.

It is not easy to be altogether cheerful when the time comes that one must surrender that which makes life worth

living, to give up one's chief interest in life, whether that be the struggle for wealth, the pursuit of happiness, or just plain every-day work. It is not easy to say—"It is done." And when one's work is also one's pleasure, when one's occupation is as interesting and absorbing as mine has been, the thought of giving it up is not made any easier.

The credit for developing a scheme of instruction in such an institution as the School of Mines must be divided. No one man can claim or should be given credit for more than a small share in the final result. We must not for a moment forget what we owe to the founders of the School of Mines, Egleston, Chandler, Newberry, Vinton and Barnard. The idea was Egleston's. His was the vision of what might be done for the country by a well-equipped school in which the sciences of mining and metallurgy should be well taught. Chandler was from the beginning the organizer and administrator. He made the idea practicable and the teaching practical and effective. Vinton was an erratic genius, a fine mathematician, an able engineer, a skilled draftsman, and he laid the foundation which made the School of Mines an engineering rather than a scientific school. At first the instruction in geology was assigned to Professor Chandler, but later the new School of Mines was fortunate in securing John S. Newberry, whose reputation as a geologist, whose experience as an administrator and whose lovable nature added much to the strength and character of the teaching force. President Barnard, scholar, mathematician, physicist and eminent educator, gave to the new school encouragement, sympathy, wise guidance and enthusiastic support.

We must not overlook the services of others, who from the beginning have contributed financial support, wise counsel, helpful guidance and personal service. President Low, President Butler, the trustees of the University, later members of the faculty, Ricketts, Hutton, Kemp, Peele, Howe, Walker, and many others, the alumni of the college and of the School of Mines, and the many benefactors, including the donor of the School of Mines building, Mr. Adolph Lewisohn.

As we all know, the new school was a success from the beginning. Planned for a few students, it had to increase its teaching force immediately. To meet the unexpected emergency, a number of the Columbia professors volunteered their

services and were enlisted in the work. Van Amringe, Peck, Rood and Joy took the subjects of mathematics, mechanics, physics and general chemistry.

The original idea was to make the School of Mines a graduate school, but it was soon found that a preparatory year was necessary. This afterward became the first year of the late four-year course. Now this preparatory work is to be relegated to the colleges and the original idea of the founders is to be given another trial. And again we call upon the faculty of Columbia College for this necessary work.

In a school for the training of engineers—the men who do things—the instruction should be practical. We have often heard Chandler tell how he wandered from one college to another in this country trying to find an institution where he could be taught chemistry in a laboratory, how he obtained his wish in a measure at Harvard, but was finally compelled to complete his education in Germany.

When the School of Mines was made ready for students, the first thing done by Chandler was to provide chemical laboratories—qualitative, quantitative and assay laboratories. Egleston had from the beginning his blowpipe laboratory and his students' collection of minerals in open drawers, as well as the show collection under glass. Vinton had his drafting rooms where the students were taught to make wonderful working drawings, like Joseph's coat in many colors.

What has been done since in laboratory equipment is familiar to everyone here present—engineering laboratories, civil, mechanical, electrical, chemical, metallurgical and mining. The summer work in surveying, in geology, in metallurgy and in mining is but an extension of the same idea.

It is not yet certain that we have exhausted the possibilities of this sort of education. It was 34 years after the founding of the school before we had laboratory instruction in physics. It will perhaps be equally long before we have laboratory work "elbow teaching" in mathematics to train the young idea, for example, to visualize mathematical conceptions involving three dimensions (and perhaps, who can say, extend such teaching to the "fourth dimension!"). I find students whose mental vision seems to be limited to a single plane, and to whom the third dimension is almost as unreal as is the fourth dimension to the rest of us. In many other

ways laboratory teaching in mathematics may prove desirable.

Not only in its laboratory and field instruction, but also in its presentation of the different subjects taught, is the School of Mines practical. Chandler's course in applied chemistry, with the Chandler museum illustrating this subject, Professor Newberry's lectures on economic geology, and his collection of ores and useful minerals, are good examples. The traditions thus established have been followed in other departments, and the School of Mines is pre-eminently a school of applied science.

A mining engineer must first be an engineer (it almost goes without saying). This has not always been recognized. When the school was organized there were few real mining engineers in the country, but many mining experts, mostly geologists. The mines were managed by the so-called practical men, and the engineering was "rule of thumb" and in the hands of boss carpenters, machinists and blacksmiths. It was fortunate that Egleston and Vinton were graduates of the Ecole des Mines of Paris and that Vinton, Peck and Trowbridge were graduates of West Point. It was most fortunate for the reputation and usefulness of the new School of Mines not only that these men were engineers, but that they had the courage of their convictions and adopted the educational traditions of the old world, instead of adapting their teaching to the existing practice of the new. The school would have been much more popular had the training been less strenuous. It would, however, never have attained its present influence and prestige.

While the School of Mines was thus organized from the beginning as an engineering school, with instruction in higher mathematics, physics, mechanics, etc., the courses in engineering were not given the prominence they deserve, and that they now have, until 1877, when Professor Trowbridge first took charge of that department, with Hutton, Crocker, Mayer, Pupin and Munroe as assistants. As an engineer, the mining engineer is called upon to design structures, headframes, bins, trestles, framed buildings; to construct reservoirs and ditch and pipe lines for water supply; to lay out roads, railways, engine and gravity planes and ropeways for the transportation of mineral; to choose intelligently, and sometimes design, machinery for mining, pumping, ventilating, hoisting and

milling, and to design power plants to operate such machinery.

Mining engineers must therefore have instruction in civil, mechanical and electrical engineering, as well as in the many special engineering problems involved in the development and operation of mines.

A mining engineer must, of necessity, be a mineralogist, geologist, and something of a metallurgist. All these subjects demand most thorough instruction in fundamental subjects—mathematics, chemistry, physics, mechanics, hydraulics, thermo-dynamics and the like. You will all remember your first and second years in the School of Mines as burdened with these subjects.

With the development of civilization and the new applications of science to the daily affairs of life, new demands are made almost every year for more detailed instruction in these fundamentals. The teaching of chemistry, physics and mechanics is today much fuller and more exacting than it was 10 years ago, and another 10 years may see further demands and further development in the same direction. Perhaps two and one-half, perhaps three years, may soon be required for fundamental science subjects. Who can tell?

From an educational standpoint the training in an engineering school must be broad and thorough in these fundamental subjects. Nothing can be permitted to interfere with this. As the course becomes more crowded, we shall have to devote less time to the professional subjects and perhaps omit many of them altogether.

From the beginning, the founders of the School of Mines determined that it should be strictly and solely a professional school. All subjects of a non-professional character, language, literature, history, philosophy, economics and the like, have been rigorously excluded. French and German were for a time included (on account of their usefulness), but later were made requirements for admission. This policy has been maintained to the present day. Other engineering schools almost without exception devote about one-fourth of the student's time to non-professional subjects and as a result weaken their professional training very seriously, and this without fully accomplishing the object desired. One year out of four is not enough time for liberal studies. It is, of course, true that our graduates are more or less handicapped by the lack of train-

ing unless they get it elsewhere, at home, at school, in college, or by their own efforts.

In 1891, when I was promoted to be the head of the new department of mining, it occurred to me that this lack of general and broad culture, so necessary for one who aspires to be a leader in his profession, could be overcome by a larger proportion of our students if they could be encouraged to attend a college before coming to the professional school. A small number of our students have a first degree on entering, and a larger number have one, two or three years of collegiate work to their credit. To take both collegiate and professional degrees then required eight years. By special arrangements at Columbia and elsewhere, the time could be shortened to seven years without losing the first degree.

The work of the first and second years in the School of Mines' four-year course was wholly of a collegiate character —mathematics, chemistry, physics, mineralogy, geology, elementary surveying and the like. There seemed to be no reason why these subjects should not be counted for the first degree and the combined course shortened to six years. A schedule of study was drawn up on these lines and submitted to my colleagues in the university, including among others Professor (now President) Butler. The idea received immediate acceptance in theory and six years later, on removal to the new site, was put into operation. For eight years this combined six-year course has been taken by a few students each year. Next year the six-year schedule will be in force for all students who may be candidates for engineering degrees.

At first the number of students will be much less than at present. The trustees have made the experiment with full knowledge of the financial sacrifice involved. It is a bold step, and one in which the outcome is uncertain. There can be no question as to the wisdom of the new course from an education standpoint, if the loss of income does not involve and make necessary economies which will affect the efficiency of instruction. No such economy is at present contemplated and we hope none will be necessary. In an educational institution increase in numbers usually increases the deficit. The education of each student always costs more than the fees paid. With few students, the annual deficit should be less.

In conclusion, I should like to say a few words as to instruction by lectures. All my academic life I have been a lecturer. No one is more familiar with the defects of the lecture system, or with its great usefulness. The chief disadvantage lies in the necessity for taking notes. But few students are skilled stenographers. If they are, their whole attention is devoted to recording the words as they fall from the lecturer's lips and the brain fails to apprehend or record the ideas conveyed. If the student takes "long-hand" notes, he must condense and so the brain takes temporary cognizance of the ideas. The more the student listens and the less he records in his notebook, the greater the impression left in his brain at the end of the lecture. The best results undoubtedly are secured by taking no notes and writing a summary afterward. I think it important, however, that the student should make his own summary. It might be well to allow 10 minutes at the end of the lecture hour for this purpose. If a printed syllabus is provided the average student pays less concentrated attention to the lecture, and the better and more complete the syllabus, the more he learns to depend upon it and the more he allows his mind to wander; or, if he follows both the syllabus and the lecturer, the printed word makes the greater impression on the brain and the spoken words are largely forgotten. With a perfect and complete syllabus, the lecture is almost, if not quite, unnecessary.

The principal advantages that may be claimed for the lecture system is that it is always up to date. The lecturer, if he is alive, will give the student the last word on the subject treated. This is especially important in engineering topics, in which every week some advance in practice is recorded in the technical press. In the case of a printed book, the proof sheets are hardly corrected before some modification or correction should be made. To bring a book up to date requires a lecture or more to supplement each chapter. The book then becomes only a less perfect syllabus.

Another advantage that can be claimed for the lecture is the possibility of elaborate illustration. If many cuts, figures, tables, formulas, or other illustrations are printed in a book, the mind of the reader is confused and strained by referring back and forth from text to illustration, and much energy is wasted and time lost in endeavoring to establish the desired

correlation. In a lecture the eye of the student can remain fixed on the diagram or blackboard, while his ear receives the explanation. In a lecture it is possible to have many diagrams on the wall and refer to one or to several at will, to illustrate the ideas to be conveyed. This would be impossible in a book without greatly fatiguing the reader.

Another advantage, and not the least important of the lecture system in good hands, is the saving of the student's time. To compile the lecture, the instructor has spent many hours in reading. A single line may represent an hour's work. If the student is required to obtain the same information, he will probably consume much more time and get only a confused and contradictory impression as the result. It is true that it is necessary for the student to learn to read intelligently and to draw accurate conclusions from what he reads. This is in itself a valuable and necessary part of his education. He should, however, not be compelled to get all of his information from library research.

Reading should supplement the lecture and should be subordinated to it. The principal disadvantage of the "case system" of teaching law and of book research in graduate work is the great expenditure of time required for the imperfect results obtained. The case system must be supplemented by recitations and lectures and the research work by seminars.

With the crowded condition of our engineering courses, in which the economy of the time of the student is of prime importance, and in which we must secure the maximum result from every hour of the student's work, the lecture system has always played an important role and will always continue to be one of the most valuable methods of imparting knowledge. Textbooks, recitations, laboratory work, reading and research should all be used, each in its proper place, but lectures should also be freely employed as giving greater results for the time expended by the student than any of the other methods.

Finally the contact between the lecturer and the student and the personal influence that may be exerted by the instructor, while present in any good form of teaching, are perhaps most effective in the lecture. Certainly in no other way can the teacher impress himself on so many in so short a time.

Many years ago Mr. Alexander L. Holley, the eminent metallurgist, read a paper on the "Inadequate Union of Engineering Science and Art." This was followed by a joint discussion by members of the several engineering societies on "Technical Education," which was afterward published in book form.

One result of this discussion was the establishment of the "Summer Class in Practical Mining" at Columbia in order to bring mining students into intimate contact with the art of mining during their professional course. In Germany, all mining students are required to spend several months in practical mining work, with considerable emphasis on manual labor, before beginning their professional training.

The summer school has proved of great advantage, as most of you will testify, but the inadequate union between science and art still obtains. Unless the graduate of the School of Mines goes through some sort of apprenticeship in practical mining, he will have indifferent success as a manager and will quickly become reduced to the ranks of "consulting engineer," in which at present the supply greatly exceeds the demand.

During the past 30 years or more, I have given much thought to this subject, and have made several tentative experiments at a graduate school of practical mining on the lines of the apprentice schools which have been established by several large corporations. None of my experiments has been altogether successful, and I question whether any such school will be of great value unless under the joint direction of an enthusiastic and capable instructor and a hard-headed and rigorous business manager. These two must work together. The apprentice must no longer be a student whose interests are all important, but he must be a wage earner, who gives full value for the wages paid. The latter result cannot be secured in any work solely under academic direction. On the other hand, the apprentice must not be looked upon primarily as a wage earner, and ruthlessly used as a cog in the machine, but he must be treated also as a student and his work so organized as to give him the necessary practical training in the shortest time. It must be recognized that his training is to make an executive officer, and that it is a waste of time to try and make him a skilled workman.

The best results so far have been secured when the enthusiastic instructor and the hard-headed business manager are one and the same person—when an officer of the company can be induced to take the graduate as an apprentice. Unfortunately, but few mine officials have the time, the training, the sympathy, and the inclination to undertake this work.

The next best thing, and one which will serve a larger number of young graduates, will be for some one or more mining companies to organize apprentice schools and delegate the supervision of the work to a competent officer of the company, who will serve in the double capacity of enthusiastic instructor and hard-headed business manager, at least, so far as the apprentices are concerned.

Such an apprentice school should prove valuable to the mining company, as well as of inestimable worth to the profession.

CHEMICAL INDUSTRY AND THE UNIVERSITY*

BY CHARLES E. LUCKE.†

It seems quite proper that a representative of mechanical engineering in the University world should be the last to speak on this topic, because, in the ordinary course of events, the mechanical engineer most follow the chemist, to provide the means for doing on a suitably large scale what has been found chemically necessary. A chemical industry centers in a factory plant, the machinery and mechanical equipment of which constitute the means whereby chemistry is transformed into chemical industry. The test-tube becomes a huge tank; the bunsen burner, a furnace fire or a steam boiler; the filter paper and glass funnel, a pump-operated filter press; the hand mortar, a power-driven crusher and grinder; the rubber hose a complicated system of piping; and the movements of the hand are replaced by a power plant with a transmission system.

The chemical industries are distinguished from the other allied manufacturing industries by the sort of processes used to convert raw material into finished product. These processes are partly chemical in nature, but never wholly so, and frequently are chemical to only a minor degree, the rest being purely mechanical, thermal, or perhaps hydraulic. Most of the apparatus for the execution of these processes is practically standardized, being made and sold in a variety of forms in standard sizes for other purposes than purely chemical ones, but as a rule each establishment must, and does, have some special equipment peculiar to its own processes, not used elsewhere. Discussions about the equipment of chemical factories or their processes tend to revolve about these special parts that are purely chemical, or peculiar to only one branch of the chemical industry, and ignore the fact, so easily established, that, taking the chemical industries as a whole, their equipment consists largely of more or less standard machinery or mechanical appliances. The significance of this is especially great in any investigation of progress in the chemical

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industries, whether the object be to discover the cause of lack of progress, or, assuming the cause to be established, to discover a remedy.

Any lack of development in the chemical industries in America cannot be traced to lack of suitable standard machinery of the sort that must necessarily comprise so large and important part of any manufacturing establishment, because such American machinery enjoys a world-wide reputation as a class, second to that of no other nation. This includes all equipment and methods for generating or transmitting power; for combustion of fuels; for absorption, exchange and dissipation of heat, including refrigeration; for changing the physical state of solids, liquids and gases; or moving, transporting, mixing and separating them; for crushing, pulverizing, consolidating, pressing, molding or cutting solids, and many others equally fundamental in importance and common in use. Improvements in this sort of equipment in quality, cost, capacity, or efficiency, arising from researches on the basic processes, on the principles of design or on use of new materials, are all available to the chemical industries, provided first, that they are known, and second, that they are adopted, and intelligently installed in cooperation with the other equipment of the plant.

This citation will serve to show that the welfare of chemical industries, while of course fundamentally resting on a chemical basis, is not exclusively a chemical question, any more than it is exclusively an engineering, or, in general, a technological question. Contributions to chemical industry along such general engineering lines may properly be classed as indirect. This indirect class is a very large one and includes activity in all the basic sciences, in economics, sociology and law, and in all related industries or industry in general. It is very easy for one vitally concerned with the chemical industries, or one branch in particular, to forget these indirect yet powerful aids, and be led into impatient complaint because of a lack of specific direct contributions to his own immediate needs. These indirect contributions are just as necessary, in their way, as a healthy body is to a successful lawyer, who however may properly be expected to known some law.

We of the modern University are students of the industries, and of the conditions that concern their general as well

as their specific welfare. Students, not in the old absorbtive sense, but in the new reactionary sense. The University of today is not a safe-depository of learning, a cold-storage warehouse of facts and principles to be carefully guarded from the world for fear someone might use them. It is, on the contrary, the digestive tract of the community, receiving all sorts of mental food, rejecting the bad, and transforming the good into those forms of energy that can be given out as new sources of vitality to all forms of activity that may be suffering from the common complaint of general debility.

Industrially, the University recognizes the primary wealth-producing industries of mining, agriculture, forestry and fisheries; the secondary producing industries of the manufactures, of which the chemical industries are but a part, and finally the industries of transportation and communication, all associated with commerce, merchandizing, and banking. Our organization does not follow just these lines of division but is arranged on the divisions of typical basic studies of the fundamental sciences, any one of which may concern itself with several or all of the industrial applications. This is one reason why the contributions of the University are not more often recognized by the industries concerned, as so many of them are indirect, bear an unfamiliar label, and require interpretation and adaptation to become directly available. Even this function of interpretation and adaptation of its general contributions to industrial use is being fulfilled by the newer elements of the University organization, through its engineering division in general and more specifically for the chemical industries, by its chemical engineering department.

Those members of the University staff that are charged with industrial responsibility are not merely students, but are really participators and direct contributors to a degree that is limited, not by any lack of interest, ability or energy, but solely by available time and money. It is freely admitted that the direct contributions to the advance of the chemical industries in America by the University have, up to the present, not been what they should be, but it can be proved that the fault is only one of degree and not of kind. Everything that should or could reasonably be expected in both the direct or indirect classes is being done to some degree, and the problem is one of ways and means, of increase in activity

of the same sort, rather than creation of a new kind. However great the indirect contributions may be, they will never serve so useful a purpose, nor receive so much recognition, nor warrant so much support, as an even moderate increase in indirect contributions made in a form directly available for immediate use, and requiring na explanations or interpretations to manufacturers concerned, for an appreciation of their value.

The most immediately available, and hence useful and valuable contribution, that any one can make to the chemical industries is new apparatus, mechanical equipment, or machinery, of proved capability to produce new and valuable results, in lessenning costs of present procedure, in making new products from the same materials, or the same products from different materials, or combining all three, new products, new materials, and reduced costs. Next in direct order of immediate value, come new processes, which, however, must be incorporated into apparatus before becoming usable.

No improvement in either apparatus or processes can be attained without an initial step in conceiving the need, on the one hand, or the possibility, on the other, and in point of time either may lead the other. Recognition of defects, or of needs, may be a part of common experience, or may be the result of a critical searching by test and computation, which should characterize the work of engineers, of the apparatus manufacturer, and of the chemical factory using the apparatus. As a matter of fact, both of these interests are so occupied with routine, and so inclined to rest on the tradition of old practice, that an outside man continuously engaged in investigating faults in all classes of apparatus can find things worth improving in almost any plant, which the regular staff often regard as sacredly perfect. This initial step of fault discovery, by investigation and comparison, is one of the regular contributions of the University staff engineer, which his independence of thought, breadth of interests, and soundness of scientific training particularly fit him to perform, and he does perform it well. This requires, however, sufficient freedom from the University routine to permit travel for inspection and tests, and an invitation and welcome by the manufacturers.

The conception of a remedy for a discovered fault or need,

or the conception of an improvement even when no need has been particularly felt or fault admitted, is the second step, the result of which is an idea, a scheme, a promising possibility. Such a conception may come to the factory man either producing or using the apparatus, or to an independent individual, or to one of the regular University staff constantly engaged in studying practices and comparing with possibilities, and is often in the form of patentable invention, though just as often it is not. This conception may be concerned with either a design for a piece of apparatus, or with a method or process for which apparatus must later be designed. In any case, its value remains a matter of speculation until apparatus is constructed and tried, to prove the soundness of the idea at least qualitatively. This step of experimental construction is the first in the series generally termed development. It necessarily costs money and often a large sum, the investment of which is in the nature of a pure speculation, and hence subject to many limitations, especially when associated, as is usually the case, with the question of legal property rights in the invention involved originally, or to be developed.

It is right here that the real barrier to great and material advancement in the chemical factory is usually to be found; it is the neck of the bottle which restricts the flow. Any number of splendid ideas have never been admitted to this first development step of experimental construction, to demonstrate their soundness and the possibilities of success, or having been permitted one trial, have been rejected and their development stopped through mistakes due to lack of skill rather than to wrong ideas; and just as many bad ideas have received experimental trials, that were never worth it. As a result the world is full of disgruntled inventors, manufacturers, promoters and bankers, to whom a new idea of this sort is a thing shunned, instead of sought. Here the staff of the research laboratory of the University can, and to some extent does contribute most valuable aid in sifting the promising from the hopeless, and in studying out the cheapest, best and most convincing experimental construction and demonstration. Especially effective is such cooperation when shop and engineering research laboratory facilities are available, so the whole procedure can be kept well in hand during this

anxious time of perplexities and trouble. This sort of work is a clearing-house operation, equalizing the debits and credits of the man of ideas and the industry concerned, and should be undertaken on a large scale with financial support to the full extent; it is now, however, being carried out on only a small scale, supported more by enthusiasm than by money and industrial appreciation.

This first step in experimental development ends with a demonstration of the soundness of the idea qualitatively, or of the bare possibility of the desired results, but still leaves open the commercial value. Proof of commercial value requires further and larger-scale demonstration on carefully designed apparatus, either of full commercial size, or truly proportioned models of smaller size, but still large enough to permit of tests for reliable data. This is usually an expensive procedure to be undertaken as a true investment, on the prospect of financial returns to follow adoption and use. While in most cases it is a proper thing for an engineering research and development laboratory, it usually involves larger equipment than any existing University laboratory can care for, and in some cases, due to the nature or the size of the equipment, must be carried out in a commercial establishment. Such commercial demonstrations, being financial enterprises of direct concern to the industries, must have industrial support, even if the work is done by the University staff; but in every case this staff can render valuable assistance by bringing to bear its broader scientific and engineering judgment unhampered by commercial traditions and jealousies. At the present time some work of this kind is being undertaken and carried through, limited only by the number of available men and facilities on the one hand, or by the willingness or unwillingness of the industrial interests to use what is to be had.

The last step in the development of new apparatus for the industries is that of commercial perfection and installation, all of which culminates in a working plant, in which the perfected apparatus is correctly associated with the existing apparatus in an old plant, or in a complete new plant with standard equipment selected so as best to cooperate with it for proper results, in quality of product and quantity of production. In this last stage the University laboratory can play no part, but its staff can, and at present does so to a limited degree,

partly in the designing of the final form of the apparatus, partly in the selection of the standard equipment to be associated with it, and in planning the connections and controls, and finally in testing for full-scale performance data, publication of which creates an industrial document, a record of results achieved, and a standard by which further suggestions for improvement must be judged. Such test results of complete plants, and the division of performance factors between the several units, are almost wholly lacking for the factories of the chemical industries, though quite common and even standard practice for other kinds of establishments, notably central power stations, shops, and many of the non-chemical manufactures.

In conclusion, it is believed that any correct analysis of the relations between the University and the chemical industries will show that the industries are receiving from the University the right kind of both direct and indirect contributions, though to an inadequate degree, and limited only by financial support, which limit, it would seem, could be removed by the industries themselves, by contributions in the reverse direction from them to the University.

VALUATION OF ANTHRACITE MINES*

BY R. V. NORRIS.†

Anthracite, though occurring in many parts of the world, is mined principally in a small area in Northeastern Pennsylvania, U. S. A. The anthracite region covers an area of about 480 square miles, estimated by Campbell to have originally contained about twenty billion tons, as compared with two trillion tons of bituminous coal in the country.

The region includes the Northern or Wyoming Field, a single basin about 55 miles long, with a maximum width of about six miles. The dips are gentle, ranging from flat to about 20°, except close to the crop and, occasionally, along anticlinals. At least 21 workable beds have been identified, with a maximum depth below the surface approximating 2500 ft., and containing a total of from 60 to 70 ft. of coal, at the most.

The Lehigh Field includes a number of small basins between the two main fields, and, by convention, also the Panther creek end of the Schuylkill basin. This field covers about 45 square miles of coal measures and is notable for steeply dipping beds, often vertical, and for the great development of the Mammoth Bed, which in places is from 40 to 60 ft. thick.

The Southern Field stretches over 44 miles of territory, with a maximum width of about eight miles and an area of 165 square miles; this field has the deepest known measures, estimated to reach to nearly 4000 ft. below the surface, with many steep dips and large beds.

The Western Middle Field is actually a branch of the Southern Field, covering an additional 94 square miles, with a length of 36 miles and a maximum width of five miles. The deepest portion will probably not exceed 3000 ft. to the bottom bed. Some twenty different beds have been mined in various portions of this region.

The problem of valuation of coal in the anthracite region is complicated by the rapid variations in the thickness and quality of the beds, by the numerous faults and still more numerous convolutions; the basins are traversed by endless

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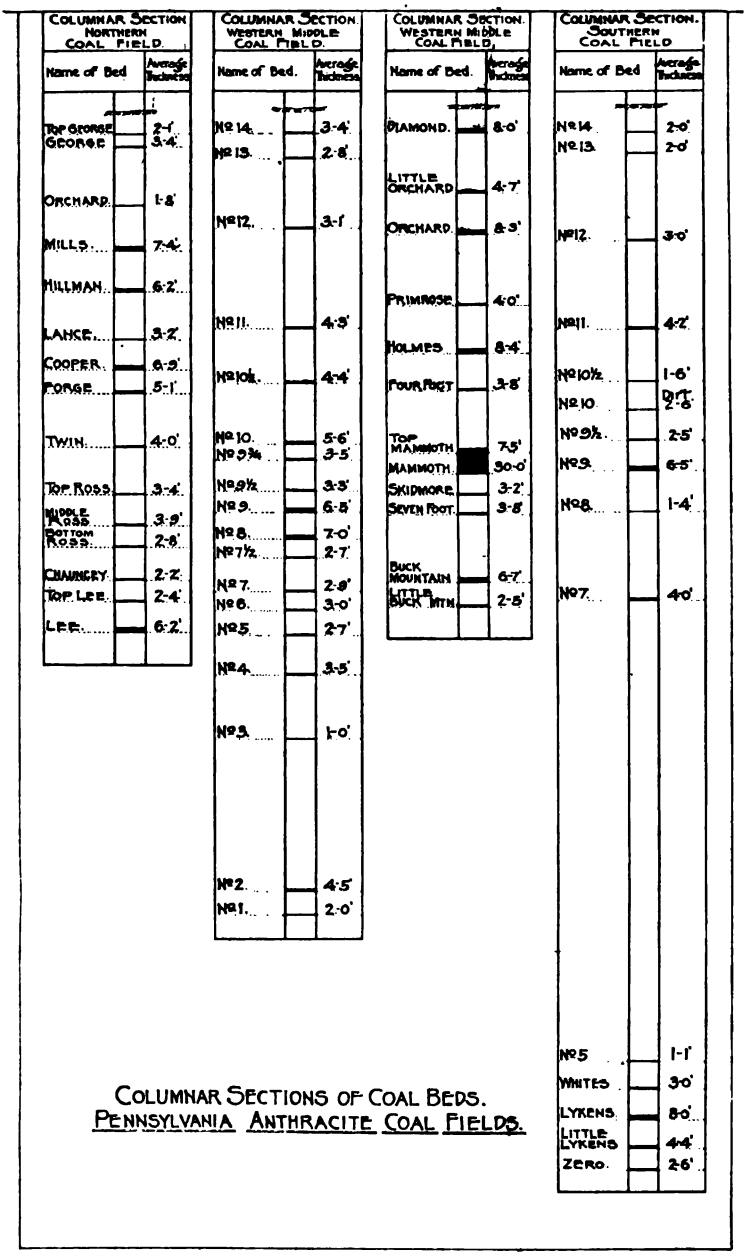
†E.M., Columbia, 1885. Consulting engineer, Wilkes-Barre, Pa.

anticlinals and synclinals, and within short distances good coal is changed to crushed and worthless dirt.



COLUMNAR SECTIONS OF COAL BEDS.
PENNSYLVANIA ANTHRACITE COAL FIELDS.

Early Valuations.

While "stone coal" was reported in 1762 by the pioneer settlers of the Wyoming Valley, was used in a forge by Obadiah Gore, a Wyoming Valley blacksmith, in 1769, and as a domestic fuel by Judge Jesse Fell of Wilkes-Barre, in 1808, its commercial use—neglecting small shipments for forge use during the Revolution and unimportant river shipments, beginning in 1807—really dates from the formation of the Lehigh Coal & Navigation Co. in 1823, a combination of the Lehigh Coal Co., incorporated in 1792, and the Lehigh Navigation Co., incorporated in 1818.

As an example of the great value put on anthracite in those days, large areas were leased to the Lehigh Coal Mine Co., 1792, for two ears of corn per year, and the great bulk of the coal-bearing lands were patented by the State of Pennsylvania, from 1795 to about 1816, on payment of $2 to $4 per acre. During the 40's and 50's of the last century $50 per acre was a good price, which, by 1875, had risen to about $500 per acre for the best land. The value rapidly increased, until at the present time $3000 per acre is considered only a fair price for good virgin coal land, and but very little of this has come on the market for many years.

Assessment Values for Taxation.

Up to nearly 1890, the assessment of anthracite lands for taxation was at nominal values, irrespective of the coal contents; the surface valuation, with but unimportant additions for the coal deposits, being adopted. At about this time agitation for a more equitable division of the burdens of taxation led to material increases in the coal valuation, and an effort to adjust this more equitably evolved the plan of assessment by the foot-acre of coal in the ground—usually reported by the owners or operators, occasionally under oath, as an average thickness spread over the area of the lowest bed. The valuation placed on the foot-acre basis, while irregular and frequentliy objectionable, was not, up to 1907, considered confiscatory, and the taxes assessed were paid without serious resistance. In 1907, stimulated by a renewed newspaper agitation, great advances were made in the assessed valuation, still on the foot-acre basis, and assessments of from $60 to $100 per foot-acre were imposed; these were resisted in the

Courts and are still (1915) in litigation, resulting in a conditions of almost intolerable chaos. Despite Court rulings reducing the assessments to from $40 to $50 per foot-acre, the valuations have been continuously increased, until at the present time assessed valuations of from $175 to $300 per foot-acre are attempted to be imposed.

All assessment for taxation in the State is based on the laws of 1841 and 1842, under which the assessors are required to "assess rate and value every subject of taxation according to the actual value thereof, and at such rates and prices as the same would bring at a bona fide sale after due notice"; and it has been ruled that the assessment value of similar properties must be equal. Under this law the Pennsylvania Supreme Court has ruled against foot-acre valuations (Report No. 229, page 465) and against royalty methods of valuation (No. 299, page 470), and has repeatedly declared that only valuations based on sales can be legally made. In the tax appeal cases tried, sales have shown prices varying from two or three hundred up to $10,000 per acre, the smaller values for land containing only relatively thin coal, or practically exhausted; medium values (from two to three thousand dollars per acre) for relatively small areas with normal coal contents, but unopened and generally not of sufficient area for separate operations; and extreme values, in a few cases, for going concerns, or for lands strategically located and thus having inflated values to particular purchasers.

The result of the long tax litigation has convinced most of the engineers and operators in the region that no equitable general basis for valuation, based on either sales, foot-acre contents, or royalty values, can be found, and only in taxation of the output can a logical and equitable solution of the problem be reached.

Further, taxation of coal measures is opposed to all principles of conservation, by putting an excessive premium on rapid exhaustion and tending to the neglect and waste of all but the most profitable beds.

Royalty Valuation.

From the general practice of mining coal on royalty, under so-called "leases"—really sales of coal in place, with payment as mining progresses,—the royalty method of valuation

has come into use; the "leases" are usually for all the coal mineable to exhaustion. Royalty rates have gradually risen from 8 or 10c. per ton, for the prepared sizes only, required under leases made in the late 60's, to 25c. per ton, prepared, in the 70's, when payment for the smaller sizes began to appear—usually, half of the prepared-coal rate for pea-coal and one-quarter of that rate for the smaller sizes; and to 40 or 50c. per ton, prepared, with proportionate rates for small coal —averaging 30 or 40c. per ton for all sizes—in the middle 80's. This rate has since been generally maintained, except in rare cases, where as high as 65c. per ton, all sizes, for coal susceptible of stripping or of exceptionally cheap mining, has been obtained.

The royalty method appears, on first thought, to be eminently logical and proper, and presents, certainly, a very simple method of valuation; it has, however, vital deficiencies.

First: That the time factor is a controlling one in royalty valuation. To illustrate: Assume five exactly similar properties, each containing 2,000,000 tons of coal to be worked out, seriatim, at an average of 100,000 tons per year, and each paying 30c. per ton royalty—an annual royalty of $30,000 paid during the mining of each tract. On the basis of present assessments, these would be valued at $400,000 and would pay approximately $8,000 per year taxes, up to the average time of exhaustion. Their present value on a royalty basis, calculated at 6%, would be as follows:

Tracts	Start Mining. Years	Complete Mining. Years	Present Value of Royalty	Less Present Value Taxes	Net Present Value
First	0	20	$344,100	$ 58,880	$ 285,220
Second	20	40	107,360	110,120	—2,760
Third	40	60	33,550	126,100	—92,550
Fourth	60	80	10,430	131,080	—120,650
Fifth	80	100	3,250	132,550	—129,300
Present value entire property...			$498,690	$558,730	$—60,040

The present value of the whole property, mined at the rate of 100,000 tons per year, is $498,690; while if the same property were mined in 20 years, at the rate of 500,000 tons per year, its present royalty value would be $1,740,500, with a deduction of but $58,880 for present value of taxes, giving a net present value of $1,681,620, against a present value of minus $60,040, including taxes, under slow mining.

Second: The royalty method of valuation does not take into account the varying conditions of mining, the widely different costs of mining thin and thick beds, the influence of depth and pitch, the character of the coal, or the cost of development; nor can a proper royalty value be placed from study of prevailing rates.

Third: Valuation on a royalty basis is weak in its assumption that all coal has the same value, and therefore may result in a valuation bearing no relation to the profits to be derived from the operation of the property.

Valuation of Tonnage

In the past, many coal valuations of important interests have been made by estimating the mineable coal remaining, and placing on it a flat value per ton, ranging from one to 10 or even 20c.; of course, such a valuation is a mere guess, based on nothing beyond the personal opinion of the appraiser, and bears no relation to the actual value of the property.

Valuation of Probable Profits

The average profit in anthracite mining, as deduced from the last census return by Mr. E. W. Parker, Statistician of the United States Geological Survey (Proceedings American Mining Congress, 1914), was, in 1900, about 20c. per ton on actual operating costs: 72,215,273 long tons produced cost $134,254,600, or $1.86 per ton; and brought at the mines $148,957,894, or $2.06 per ton. The capital invested was reported at $246,700,000; hence the average profit shows a return of a little less than 6% on the capital invested, without any allowance for depreciation of improvements nor for depletion of properties. If but 5c. per ton is allowed for exhaustion of properties, the return is reduced to about 4½%, from which a deduction must still be made for the amortization of improvements.

It would seem to be logical to assume that the value of a mining property will be best expressed by the present value of the ultimate product less the present value of the cost of its production, in other words, by a capitalization of the profits.

Unfortunately, such a method of valuation is exceedingly difficult, involving many and tedious calculations and long study of conditions, and while at the best but an approxima-

tion, with sufficient study it appears to give results more logical and probably more nearly correct than any of the methods previously discussed.

In general, the variables which must be determined comprise four classes of factors: labor conditions; prices; output (controlled by market and physical conditions); and mining cost.

Labor Conditions

In the anthracite region, as has been shown, the average margin of profit is so small that increases in labor rates have been, and must always be, accompanied by equalizing increases in selling price; hence the factor of increasing wages—and the increase has approximated 45% in the last 15 years—may reasonably be balanced against increasing prices, and the importance of the factor of labor conditions is thus minimized and may be disregarded without introducing probable serious errors.

Prices.

The selling price of anthracite has been held practically stationary, except for increases due to labor increases, for many years; the average for the last 10 years, $2.28 per ton f. o. b. mines, compares with $2.39 for 1913. The principle controlling this has been enunciated by the late Mr. George F. Baer, in his testimony before the Interstate Commerce Commission:

> "The price of the entire supply of anything necessary for a community will be regulated by the cost of production of that portion of the necessary supply which is produced at the greatest expense."

As will be shown, the greatest expense of production is from thin and steeply pitching beds; and a sufficient portion of the necessary supply must be drawn from these to make negligible the probability of any material decrease of price. On the other hand, the constant competition of other fuels makes any material increase beyond that required to equalize increased cost of mining improbable. Hence, the present average margin over labor costs may, with reasonable safety, be assumed for at least some years in the future, and as the results of the earlier years have a preponderating influence on

the valuation, the market price may be obtained with reasonable accuracy.

Output.

The market for the domestic sizes of anthracite has been shown to vary practically directly with the population of the consuming territory (Mineral Resources of the U. S., 1905, p. 658). For the years 1889 to 1891, it averaged 1.17 tons per capita and for 1903 to 1905, 1.11 tons; and as population is increasing faster than the output can possibly be increased, a constantly increasing market for the domestic sizes seems assured. For the steam sizes, the market per capita of population, for the same periods, has increased from 0.50 to 1.00 ton; and as the percentage of steam sizes available must decrease, owing to greater colliery demands for fuel, with the extension of the workings both longitudinally and in depth, and the rapid reduction of the supply from the washing of the old banks, assurance may be felt as to the continuance of a market for these sizes on a competitive basis with bituminous coal. The price of bituminous coal is more likely to rise than to fall, and can hardly fall materially, in view of the present small profits, shown by the last census (E. W. Parker, American Mining Congress, 1914) to be about 2½% on the capital invested, or about 7c. per ton, to cover interest, amortization and depreciation, to say nothing of profit.

Thus there appears to be an assured market for all probable production, the increase of which is much less rapid than formerly and which has apparently nearly reached its apex. The percentage of increase by ten-year periods has been approximately as follows:

Period	Production	Percent Increase
1823	6,951	.....
1833	487,759	.....
1843	1,263,598	159 %
1853	5,195,151	313 %
1863	9,556,006	804 %
1873	21,227,952	122 %
1883	31,793,027	49 %
1893	43,089,537	35 %
1903	59,362,831	38 %
1913	69,069,628	16½ %

Apparently, therefore, it is reasonably safe to assume that the present relation between labor prices and selling price can at least be maintained, and that, as far as physical

conditions permit, the output of any colliery can probably be gradually increased without overstocking the market; hence, the main variables to be taken into account in a valuation of probable profits are the cost of mining and the output of any colliery.

Mining Costs.

Mining costs may be divided generally into cutting and loading coal (including normal development), general inside costs (timber, transportation, hoisting, pumping, ventilation, royalty, and supervision), and outside costs (preparation, transportation, disposal of refuse, supervision, and general office costs). Of these, the inside costs have been found generally to vary directly, in any colliery, with the cost of cutting and loading, which, in turn, varies with the character, thickness, and quality of each bed; while the outside cost is independent of the character of the coal.

In the valuation of an operating colliery, the cost of cutting and loading in each bed can be obtained, and an average future cost for the entire mine can be predicted from an average of the individual bed costs, weighted in the proportion of each bed remaining; this computed cost may be, and usually is, far different from the present cost, as it will usually be found that much more than the average percentage remaining is being mined from the better and cheaper beds.

The principal varying factors in individual bed cost are thickness, pitch, depth, and character of coal.

Influence of Thickness of Coal.

The beds in the anthracite region vary from 2½ to 60 ft. thick, and from nearly pure benches of great thickness to beds with inch layers of alternating coal and refuse; hence, no hard and fast formulas for the relation between thickness and cost are possible. In flat measures, the average of a very large number of costs, in different collieries, has shown that the lowest mining cost is for coal from 6 to 7 ft. thick, and taking this as a base, the average increase of cost for thinner beds approximates the following: 5 ft. thick, 10% increase; 4 ft., 25%; 3ft., 50%; 2½ ft., 70%; and 2 ft., 100%.

Influence of Pitch of Coal

The actual wages paid in pitch mining are practically the same as in flat mining; the difference in cost comes from the

smaller yield of the beds. Taking the original contents removed, corrected for pitch, as a base, the yields for varying pitches approximate as follows:

Flat	82%	50 degrees	55%
10 degrees	80%	60 "	54%
20 "	75%	70 "	53%
30 "	68%	80 "	52%
40 "	61%	90 "	50%

Influence of Depth.

Sufficient mining at great depth has not yet been done in the anthracite region to give actual ultimate figures of yield under varying conditions. For first-mining yield, Bunting's formula (Trans. A. I. M. E., Vol. 42, p. 236) gives for normal flat measures the safe percentage of removal for varying depths and thicknesses of bed.

$$P^2 + \left(\frac{7}{3}T - \frac{DT}{300}\right)P = \frac{CDT}{300}$$

P = Pillar with
T = Total thickness of bed
C = Chamber width
D = Depth in feet

Assuming a 6-ft. bed, the percentage of safe removal in first mining would be: for less than 600 ft. depth, 60%; 800 ft., 53.4%; 1000 ft., 46½%; 1200 ft., 44½%; 1500 ft., 40%; and 2000 ft., 34.2%, with an unknown additional percentage for second mining.

In 1913 a committee of the chief mining engineers of the greater operating companies accepted as a basis of safe removal a scale based on both depth and thickness.

Bed Thickness	Depth Below Surface							
	0 to 500 ft.		500 to 1000 ft.		1000 to 1500 ft.		1500 to 2000 ft.	
	Percentage Safely Removable							
	Flat	Pitch	Flat	Pitch	Flat	Pitch	Flat	Pitch
2½— 6 ft.	79%	75%	66%	63%	55%	52%	46%	44%
6 —10 ft.	75	71	63	60	52	49	43	41
10 —14 ft.	71	67	59	56	48	46	40	38
14 —20 ft.	68	65	56	53	45	43	37	35
20 —30 ft.	65	62	53	50	43	41	35	33

Influence of Character of Coal

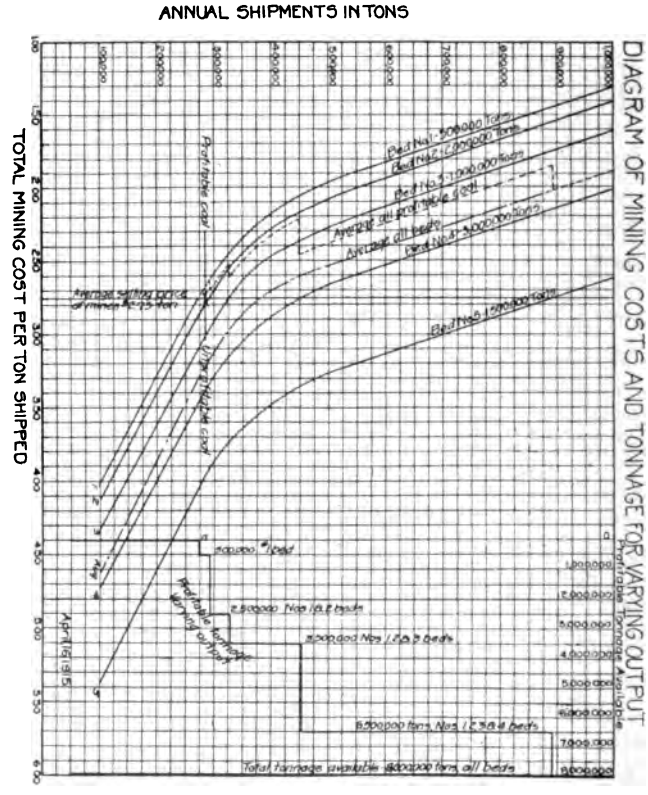
This must be studied separately in each colliery and each bed, with the general assumption that badly laminated beds or those containing soft or crushed coal are much more costly to mine than similar beds of pure hard coal; and further, that the yield from such soft or laminated beds is far less than normal.

Influence of Output on Cost

A properly designed colliery should be equipped, in the broadest sense, for the particular output best suited to its condition, and variations from this will have a material influence on the cost of production: a decrease of output from the standard very rapidly raises cost, and an increase reduces them, but not to so great an extent. By obtaining the operating costs of a colliery through a considerable term, it is usually possible to plot the various items of cost in relation to output in the form of a curve, for present conditions; then from this curve, with the variation from the average of the cost in each individual bed, a curve of inside cost for varying output may be obtained for each bed, which, combined with the curves for outside and overhead costs, will give a curve for total cost in each bed for varying output. Then an average curve from these, weighted by the percentage remaining in each bed, may be obtained, representing the probable average future cost for all beds remaining. The bed-cost curves thus obtained, further show clearly, by locating a line of average sale price, the profitable and unprofitable beds at each output; and a curve of "profitable coal" may be drawn indicating the future probabilities of the colliery, mining only such coal as shows a profit at any particular output.

As an example of this, the accompanying diagram shows the separate costs in the five beds of an anthracite colliery, taken from actual practice; but taking averages of several beds in different collieries, assuming that 500,000 tons remain in No. 1, 2,000,000 in No. 2, 1,000,000 in No. 3, 3,000,000 in No. 4 and 1,500,000 in No. 5 bed, the average future cost, assuming present conditions, is shown by the line marked "Average of all Beds". A weighted average of the bed curves and the distance of the curves from the vertical line of "average selling price at the mine", taken at an average of $2.75 per ton for all sizes, shows at once the probable profit or loss in mining any or all beds at any output. At the point where the bed curve crosses the selling-price line, the coal in that bed becomes unprofitable and from a weighted average of the profitable coal to the left of the price line, the line of all profitable coal may be drawn. Thus, at 400,000 tons output, the average cost for all beds would be $2.70 per ton, a profit of 5c. on 8,000,000 tons, or a total profit of $400,000; while at

the same output, mining only profitable coal, the cost would be $2.33 per ton, a profit of 42c. on 3,500,000 tons, or a total profit of $1,470,000, but with a loss of 4,500,000 tons of coal. On the right-hand side of the diagram, the profitable tonnage for each output is shown, varying from 0, below 275,000 tons output, to the total 8,000,000 tons available, above 890,000 tons per year output.


ANNUAL SHIPMENTS IN TONS
TOTAL MINING COST PER TON SHIPPED
DIAGRAM OF MINING COSTS AND TONNAGE FOR VARYING OUTPUT
Profitable Tonnage Available
Profitable Cost
Total tonnage available 8000000 tons all beds

While the curves for all collieries thus far tested take the general form of a hyberbola, the inclination of the axis and the position of the apex depend upon the characteristics of the beds, the extent of the colliery and its equipment. The apex will usually appear at about the rated output of the colliery—in the diagram, about 400,000 tons per year—and the curves will approach a straight line at the limit of the colliery's capacity—on the diagram, about 550,000 tons.

Future Production.

From the equipment of any colliery, its past history as to production, and the quantity and distribution of coal remaining, a fairly accurate prediction of the probable future production, decreasing as the colliery nears exhaustion, may be made. Plotting this probable future production in a curve, and combining with the curves of average cost for each period, allow a fair prediction of the probable future profits, which, discounted, gives a present value for any colliery as a going concern. To such value must be added the present value of the surface lands and remaining improvements at the exhaustion of the work; but with long-lived operations, such present values are small and the influence of errors not important.

Treatment of Improvements.

It is evident that if a given virgin property has a gross earning capacity, with a present value, of, say, $1,000,000, while the present value of the improvements necessary to produce such earning capacity is, say, $400,000, then the present value of the property is not $1,000,000, but $600,000; hence, in a going property, the improvements and developments already made, except for their scrap value at the close of operation, may be neglected in a valuation based on future earnings; but any future improvements, required to obtain the coal in place, must be deducted at their present value from the present value of the earnings. In practice, it is impossible to forecast all such future improvements, but major improvements, as new shafts, new main tunnels, breakers, etc., may be taken into account in this way; and for minor improvements, an average cost per ton, based on past experience may be added to the general cost.

The methods of valuation above outlined are of course applicable only to a mineral such as coal, the extent and quan- of which is susceptible of reasonably accurate estimation; and owing to the labor involved and the great cost of the necessary examinations, both of the physical conditions and of the books, this full procedure is probably justified only in the valuation of important properties.

THE CHEMISTRY OF FURNACE EFFICIENCY AND AIR SUPPLY.

BY C. E. LUCKE AND E. D. THURSTON, JR.

The efficiency of a furnace, or, indeed, of combustion in general, is merely the ratio of the heat actually produced by burning the fuel to the amount originally contained therein. This is equivalent to the heat in the fuel less the combustion losses divided by the heat in the fuel or

$$(1)\quad \text{Furnace efficiency} = 1 - \frac{\text{loss on combustion.}}{\text{heat originally in fuel.}}$$

These losses occur in the incomplete combustion of carbon to carbon monoxide (CO) instead of to carbon dioxide (CO_2), and in the failure to consume all of the hydrogen and hydrocarbons in the fuel. The latter may be considered as marsh gas (CH_4) as the higher hydrocarbons will break down to form this gas during combustion.

Values for furnace efficiency may be experimentally determined or approximately predicted by empiric equations based on previously determined experimental results. However, by resorting to the chemical equations expressing the reactions occurring during combustion there may be deduced a rational expression for furnace efficiency in terms of the carbon content of the fuel and the composition of the products of combustion as determined from the flue-gas analysis.

Starting with the reaction equations for carbon combining with oxygen to form carbon monoxide and carbon dioxide, Eqs. (2) and (3), and by assuming that the molecular weight in pounds of each of the products formed occupies 358 cu. ft. under standard conditions of pressure and temperature, Eqs. (4) and (5) result:

(2) $C+O_2=CO_2+14{,}544\times 12$ B.t.u.

(3) $2C+O_2=2CO+(4{,}351\times 12)2$ B.t.u.

(4) 1 lb. $C+\left\{\begin{matrix}\frac{32}{12}=2.66\text{ lb.}\\ \text{or}\\ \frac{358}{12}=29.8\text{ cu. ft.}\end{matrix}\right\}O_2$

$$=\left\{\begin{matrix}\frac{44}{12}=3.66\text{ lb.}\\ \text{or}\\ \frac{358}{12}=29.8\text{ cu. ft.}\end{matrix}\right\}CO_2+14{,}544\text{ B.t.u.}$$

$$(5)\quad 1\text{ lb. C} + \left\{\begin{matrix}\frac{8}{3}\frac{3}{4}=1.33\text{ lb.}\\ \text{or}\\ \frac{8}{3}\frac{5}{4}\frac{8}{4}=14.9\text{ cu.ft.}\end{matrix}\right\}O_2 = \left\{\begin{matrix}\frac{5}{3}\frac{6}{4}=2.33\text{ lb.}\\ \text{or}\\ \frac{8}{3}\frac{5}{4}\frac{8}{4}\times\frac{2}{3}=29.8\text{ cu.ft.}\end{matrix}\right\}CO + 4{,}351\text{ B. t. u.}$$

For air, O_2=23.1% and N_2=76.9% by weight.

O_2=20.9% and N_2=79.1% by volume.

N_2=3.33 × weight of O_2, and 3.78 × volume of O_2.

Air = 4.73 × weight of O_2, and 4.78 × volume of O_2.

Substituting air for oxygen, Eqs. (4) and (5) become Eqs. (6) and (7) below:

$$(6)\quad 1\text{ lb. C} + \left\{\begin{matrix}11.517\text{ lb.}\\ \text{or}\\ 142.44\text{ cu. ft.}\end{matrix}\right\}\text{air} = \left\{\begin{matrix}\left[\begin{matrix}3.67\text{ lb.}\\ \text{or}\\ 29.8\text{ cu. ft.}\end{matrix}\right]CO_2\\ +\\ \left[\begin{matrix}8.857\text{ lb.}\\ \text{or}\\ 112.64\text{ cu. ft.}\end{matrix}\right]N_2\end{matrix}\right\} + 14{,}544\text{ B. t. u.}$$

$$(7)\quad 1\text{ lb. C} + \left\{\begin{matrix}5.759\text{ lb.}\\ \text{or}\\ 71.22\text{ cu. ft.}\end{matrix}\right\}\text{air} = \left\{\begin{matrix}\left[\begin{matrix}2.33\text{ lb.}\\ \text{or}\\ 29.8\text{ cu. ft.}\end{matrix}\right]CO\\ +\\ \left[\begin{matrix}4.429\text{ lb.}\\ \text{or}\\ 56.32\text{ cu. ft.}\end{matrix}\right]N_2\end{matrix}\right\} + 4{,}351\text{ B. t. u.}$$

Let X=fraction of a pound of carbon burning to CO_2.

1-X=fraction of a pound of carbon burning to CO.

Multiplying Eq. (6) by X and Eq. (7) by 1-X, and adding, Eq. (8) results when no excess air is supplied.

$$(8)\quad 1\text{lb.C} + 5.759(1+X)\text{lb. air} = \left\{\begin{matrix}29.8X\text{ cu. ft. }CO_2\\ +\\ 29.8(1-X)\text{ cu. ft. CO}\\ +\\ 56.32(1+X)\text{ cu. ft. }N_2\\ +\\ (10{,}193X+4{,}351)\text{B.t.u.}\end{matrix}\right.$$

The corresponding equations for hydrogen combustion are given below as Eqs. (9), (10), (11), the lower heating value of hydrogen being chosen. It will be noted that the volume of the water vapor formed is zero, as the vapor will con-

dense to water at the temperature at which the analysis of the products is made, and the volume in the liquid form is infinitely small as compared with that in the vapor condition.

(9) $2H_2+O_2=2H_2O+4\times51{,}892$ B.t.u.

(10) 1 lb. $H_2+\left\{\begin{matrix}\frac{8}{1}=8\text{ lb.}\\ \text{or}\\ 8\frac{5}{4}=89.5\text{ cu.ft.}\end{matrix}\right\}O_2$

$$=\left\{\begin{matrix}\frac{8}{1}=9\text{ lb.}\\ \text{or}\\ \text{zero cu.ft.}\end{matrix}\right\}H_2O+51{,}892\text{ B. t. u.}$$

(11) 1 lb. $H_2+\left\{\begin{matrix}34.64\text{ lb.}\\ \text{or}\\ 427.8\text{ cu. ft.}\end{matrix}\right\}\text{air}=\left\{\begin{matrix}\left[\begin{matrix}9\text{ lb.}\\ \text{or}\\ \text{zero cu. ft.}\end{matrix}\right]H_2O\\ +\\ \left[\begin{matrix}8\text{ lb.}\\ \text{or}\\ 338.3\text{ cu. ft.}\end{matrix}\right]N_2\end{matrix}\right\}+51{,}892\text{ B. t. u.}$

All fuels are composed, so far as the combustible goes, of carbon and hydrogen, with possibly a very small and in all cases a negligible amount of sulphur.

Let C^1=fractional part by weight of the combustible existing as carbon, free or combined;

And $(1\text{-}C^1)$=fractional part by weight of the combustible existing as hydrogen, free or combined.

Multiply Eq. (8) by C^1, and Eq. (11) by $(1\text{-}C^1)$, and add, forming Eq. (12):

(12) $\left\{\begin{matrix}C^1\text{lb. C}+(1-C^1)\text{lb.H}_2\\ \text{or}\\ 1\text{ lb. combustible}\end{matrix}\right\}+\left\{\begin{matrix}5.759(1+X)C^1\\ +\\ 34.64(1-C^1)\end{matrix}\right\}\text{lb. air}$

$$=\left\{\begin{matrix}29.8XC^1\text{ cu. ft. CO}_2\\ 29.8X(1-C^1)\text{ cu. ft. CO}\\ 56.32(1+X)C^1+338.3(1-C^1)\text{cu. ft. N}_2\\ (10{,}193X+4{,}351)C^1+51{,}892(1-C^1)\text{ B.t.u.}\end{matrix}\right.$$

which may be simplified as in Eq. (13):

(13) 1 lb. combustible $+(34.64-28.88C^1+5.759XC^1)$lb. air

$$=\left\{\begin{matrix}29.8XC^1\text{ cu. ft. CO}_2\\ +\\ 29.8(1-X)C^1\text{ cu. ft. CO}\\ +\\ 338.3-282C^1+56.32XC^1\text{ cu. ft. N}_2\\ +\\ 51{,}892-47{,}541C^1+10{,}193XC^1\text{B.t.u.}\end{matrix}\right.$$

In the above, the only variables are X and C^1, the former being obtained from the flue-gas analysis and the latter from the ultimate analysis of the combustible of the fuel.

From Eq. (8) it will be seen that the ratio of the volume of CO to the volume of CO_2 in the products is $(1\text{-}X) \div X$, or the same as the fractional weight of carbon burning to CO and to CO_2. Since

$$\frac{CO}{CO_2} = \frac{1-X}{X}, \quad X = \frac{CO_2}{CO_2+CO} \text{ and } 1-X = \frac{CO}{CO_2+CO}$$

When no CO is formed, or combustion of carbon is complete, $X=1$, and the heat produced in Eq. (8) becomes $51{,}892-37{,}348C^1$; hence

$$\text{Furnace efficiency} = \frac{51{,}892-47{,}541C^1+10{,}193XC^1}{51{,}892-37{,}348C^1} \quad \text{(a)}$$

(14)

$$= 1-\frac{10{,}193C^1(1\text{-}X)}{51{,}892-37{,}348C^1} \quad \text{(b)}$$

$$= 1-\frac{10{,}193C^1\left(\frac{CO}{CO_2+CO}\right)}{51{,}892-37{,}348C^1} \quad \text{(c)}$$

Eq. (14) holds true if there be no unburned hydrogen or hydrocarbon, and is in terms of carbon content and flue-gas.

As an example, consider a coal, the combustible of which gave an ultimate analysis of 95%C and 5% H_2, and for which, on combustion, the flue-gas analysis proved to be CO_2, 12%; CO, 3.8%; O_2, 4.7%, and N_2, 79.5%. From Eq. (14)c,

$$\text{Effic.} = 1-\frac{10{,}193\times0.95\times\frac{3.8}{3.8+12}}{51{,}892-27{,}348\times0.95} = 86\%$$

Should there also be CH_4 and H_2 in the flue-gas, the heat loss for each must be separately determined and subtracted from the available heat. This may be done as follows: From Eq. (13) it will be seen that the volume of $CO+CO_2$ per pound of combustible is $29.8XC^1+29.8(1\text{-}X)C^1=29.8C^1$ cu. ft.; hence the cubic feet of H_2 or CH_4 per cubic foot of CO_2+CO, if multiplied by $29.8C^1$, will give the cubic feet of each per pound of combustible; and if these amounts be multiplied by the heat of combustion per cubic foot of the respective gases, the heat loss to be deducted from the fuel will be found. The heat of combustion of H_2 per cu. ft. is 292 B. t. u., and of CH_4, 959 B. t. u.

Hence heat loss per pound of combustible due to H_2 is

$$\frac{H_2}{CO+CO_2}\times29.8C^1\times292 = 8{,}702C^1\left[\frac{H_2}{CO_2+CO}\right]$$

and that due to CH_4 is

$$\frac{CH_4}{CO+CO_2}\times 29.8C^1\times 959=28{,}578C^1\left[\frac{CH_4}{CO_2+CO}\right]$$

while that due to CO, as already determined, is

$$10{,}193C^1\left[\frac{CO}{CO_2+CO}\right]$$

The sum of these will give the total loss, and the general equation then for furnace efficiency is Eq. (15), which reduces to Eq. (14) when H_2 and CH_4 are zero.

(15) Furnace efficiency =

$$1-\left[\frac{C^1}{CO_2+CO}\right]\left\{\frac{10{,}193CO+8{,}702H_2+28{,}578CH_4}{51{,}892-37{,}348C^1}\right\}$$

As an example, consider the same coal as before, and a flue-gas analysis of CO_2, 11%; CO, 3.4%; O_2, 4.7%, H_2, 1.1%; CH_4, 0.3%; N_2, 77.5%. From Eq. (15), Effic.=

$$1-\frac{0.95}{0.144}\left\{\frac{10{,}193\times 0.034+8{,}702\times 0.011+28{,}578\times 0.003}{51{,}892-37{,}348\times 0.95}\right\}=78.7\%$$

From the flue-gas analysis can also be determined the actual amount of air supplied for combustion. When excess air is used, both oxygen and nitrogen will be added to the in air is constant and equal to 3.78, the amount of oxygen present $\times 3.78$ will give the nitrogen belonging the excess air, and the remainder must have come from the combined air, or that actually utilized for combustion. As the ratio of two amounts of air is the same as that of the respective amounts of nitrogen in each, it follows that

$$(16)\qquad \frac{\text{Excess air}}{\text{Combined air}}=\frac{3.78O_2}{N_2-3.78O_2}$$

The total air will, of course, be the combined plus the excess.

As an example, consider the flue-gas and coal previously assumed. From Eq. (13) the combined air is

$$34.64+28.88\times 0.95+5.759\times\frac{12}{15.8}\times 0.95=11.36 \text{ lb.}$$

From Eq. (16), excess $=11.36\times\dfrac{3.78\times 4.7}{79.5-3.78\times 4.7}=3.25$ lb.

Total air=11.36+3.25=14.61 lb. per pound of combustible.

DEPARTMENTAL REPORTS FOR 1914-1915

Chemistry.

Changes in Staff.—Dr. Neish and Dr. Nelson were promoted to be assistant professors. Dr. Murphy, instructor in Chemical Engineering, resigned, and two assistants, C. E. Davis and P. L. Davis, were appointed in his place.

New Courses.—Additional sections in inorganic chemistry and qualitative analysis were added. New courses in the history of chemistry by Dr. Barry, and on colloids, by Dr. A. W. Thomas, were given. Seminar or conference courses in inorganic and analytical chemistry, and in engineering and electro-chemistry were introduced.

General and Inorganic Chemistry.—Registration in College inorganic chemistry has greatly increased.

In research, Professor Smith and Dr. Calvert have published measurements of the dissociation pressures of the ammonium and substituted ammonium halides. Dr. Calvert has also worked upon the vapor pressures and other properties of soap solutions and upon the properties of aluminum chloride. Professor Smith and Dr. Lombard have published a study of the composition of the saturated vapors of the ammonium halides, and have completed a similar study of the vapor of phosphorus pentachloride, and an investigation of the dissociation pressures of extremely dry ammonium chloride and calomel. Dr. Barry has published a general study of the influence of temperature on chemical reactions and has continued his exact thermochemical work. Dr. Kendall has published three new papers on addition compounds of organic substances, a paper on ionization equilibrium in solution, and a paper on a formula for representing the heats of vaporization of non-associated liquids.

Professor Smith has published a "Laboratory Outline of Elementary Chemistry." A translation of his "Inorganic Chemistry" into Portuguese, by Professor De Sousa Gomez, has appeared. Professor Smith has also delivered addresses on various aspects of the teaching of chemistry before the New England Association of Chemistry Teachers, the Virginia Chemists' Club, and the New Jersey Science Teachers' Association; also an address on sulphur before the Boylston Chemistry Club of Harvard University. Professor Smith was elected to membership in the National Academy of Sciences at its Spring meeting.

Professor Neish gave a course of nine lectures on industrial chemistry in connection with the public lecture system of the New York Board of Education.

Physical Chemistry.—Three papers have been published by Professor Morgan: "Influence de la temperature sur la tension superficielle du Mercure dans la Vide." *Annales de Physique*: 9, 7, pp. 826-340. "Das Tatesche Gesetz." *Zeit. f. Phys. Chem.*: 89, pp. 385-410. "The drop weight method for the determination of the surface tension of a liquid." *Jour. Am. Chem. Soc.*, June, 1915.

Two other investigations have been completed: "The surface tensions of water-sulphuric acid mixtures, and a study of the compounds produced in the system," with C. E. Davis. "The surface tensions of water-phenol mixtures, and a study of the compounds existing in the system, with G. Egloff.

The fifth, revised edition of Professor Morgan's "Elements of Physical Chemistry" has been issued.

Organic Chemistry.—The tremendous development of organic chemistry during recent years, and its present great interest for this country, have led Professor Bogert to change his lectures in advanced or-

ganic chemistry from a one-year to a two-year course, in order to have time to discuss more adequately the many important branches of the subject. The various chapters will be so selected as to cover the native field in two years. The first year will be devoted chiefly to the study of the non-nitrogenous organic compounds, and the second year to the nitrogenous.

Professor Nelson and Dr. Falk have published their sixth paper on the electron conception of valence. Under Professor Nelson's guidance, Mr. E. G. Griffin has completed his investigations of certain new derivatives of pinite and inosite.

At the annual meeting of the American Philosophical Society, in Philadelphia, April 23, 1915, Professor Bogert presented papers dealing with the discovery of a new cymene carboxylic acid and the synthesis of its little known isomer, also on certain new deriviatives of syringic acid; and on two new forms of receiver for fractional distillations under diminished pressure, which permit collecting any number of fractions of any desired volume. Professor Bogert has been elected to membership in the American Academy of Arts and Sciences and in the National Institute of Social Sciences.

During the year the laboratories received gifts of over 2000 rare chemicals through the courtesy of Dr. Hugo Schweitzer and Mr. Albert Plaut.

Food and Sanitary Chemistry.—Mr. A. W. Thomas, instructor in food chemistry, completed his investigation of "The Influence of Certain Acids and Salts upon the Activity of Malt Amylase", and in February received the degree of Ph.D. During the second half-year he has given a new course in the chemistry of colloids. In March, Dr. Thomas lectured before the New York Academy of Sciences upon the "Action of Diastase Upon Starch."

Professor Sherman is serving as research associate of the Carnegie Institution, and as a member of the National Commission on Milk Standards, of the advisory council of the New York Department of Health, and of the bureau of food supply of the New York Association for Improving the Condition of the Poor.

Chemical Engineering.—The laboratory work has been somewhat extended, and some of the operations have been materially changed. Under the direction of Professor Whitaker, Mr. C. M. Alexander completed an investigation of the cracking of petroleum. He studied particularly the effects of varying the rate of feeding, and found that the proportion of illuminants could be decreased or increased by changes in this factor, which is easily controlled, just as well as by changes in the temperature and pressure, which are more difficult to control. A workable method of control which will probably be of commercial value has thus been devised.

Professor Whitaker lectured before the Rochester section of the American Chemical Society on some chemical problems involved in chemical manufacture, and received the degree of Doctor of Chemical Engineering from the University of Pittsburg.

Electro-Chemistry.—The course has been extended so as to include the preparation of sodium, the electrodeposition of brass, and other experiments. Under the direction of Professor Tucker, Mr. Alexander Lowy has completed a research on the preparation, properties, and composition of silundum. Professor Tucker has prepared a chapter on laboratory electric furnaces for a book on the electric furnace, edited by W. McA. Johnson.

General.—An anonymous gift of $30,000 has been made to the department for the purpose of refitting the quantitative and organic laboratories, and providing equipment for a course in quantitative technical analysis.

ALEXANDER SMITH.

Civil Engineering.

The work of the Department of Civil Engineering may now be considered as covering completely the regular courses in civil engineering and sanitary engineering, and the graduate work in highway engineering. While there are still a few details to be perfected in the actual work of instruction in sanitary engineering, it may be considered complete in all its essential features, especially since the appointment of Mr. Gustav Tuska as lecturer on street cleaning and the disposal of municipal wastes. It is a great gratification to me and a matter of felicitation for the University to have attained at last a complete course of study in sanitary engineering, as this is a professional field of great moment not only to municipalities but to all communities where both public and private health are concerned.

Although the regular subjects of the department have long since reached a more or less permanent condition, affording little or no opportunity for marked progress in essential features, it should be stated that even such subjects are administered with alert attention to progress in parallel parts of current professional work. This is particularly true of such prominent subjects as railroad construction and operation; the broad field of masonry construction, including both plain and reinforced concrete; hydraulics; all branches of iron and steel design, especially in relation to the gradual displacement of pin-connected structures by those with riveted joints; sanitary engineering, including sewerage and treatment of public water supplies; as well as subjects relating to the furnishing and development of power, as given in other engineering departments. I believe it is true that all these subjects, as well as others less prominent, are kept fully abreast of the best professional practice.

It may be proper to indicate here a feature frequently commented upon among instructors: that is, the apparent inability or reluctance of engineering students, in general, to exhibit initiative in their regular routine work, although ready in most cases to undertake daily work laid out for them in detail. This is a serious deficiency in the attitude of the student, difficult to combat successfully, and indeed, serious enough to merit the earnest consideration of the instructing body. Professional students should certainly be encouraged and stimulated to take an attitude of forceful initiative toward their work, especially during the last two years of their course of study. No effort should be omitted to stir up that kind of interest which prompts self reliance and intelligent initiative.

These considerations have induced the Department of Civil Engineering to put the thesis work of the graduating students upon a wholly individual basis. As I have indicated in my previous reports, every fourth-year civil engineering student is charged with the responsibility of selecting his own subject and treating it on his own judgment in every particular, although he is at liberty to secure information of every description from anyone who can give it, or from any source from which it may best be drawn. The results of the current year have been no less satisfactory in this part of the department's work than heretofore. Although the theses naturally lack the characteristics of ripeness and experience, in the main they are highly creditable, and justify the confidence placed in their authors. They show that our students are capable of producing excellent results on their own initiative when opportunity is offered.

Graduate Work in Highway Engineering.—This part of the work of the department shows encouraging results for the year. Sixty-six graduate students have registered, an increase of 13 over last year. The following fields of work were represented: State highway departments, nine; county highway departments, seven; municipal highway departments, 17; consulting engineers' offices, five; contractors' engineering

organizations, nine; university faculties, three; engineering departments of companies manufacturing road and paving machinery, 10; engineering, research, and chemical departments of companies manufacturing road and paving materials, six. It is also of interest to observe that 20 American universities were represented by their graduates. Eleven graduate students have satisfactorily fulfilled the requirements and will receive the degree of Master of Arts, as compared with four a year ago.

During the year 15 lectures on highway engineering were given by prominent engineers from New York City, Boston, Newark, N. J., Philadelphia, and Baltimore. These lectures form a valuable adjunct to the regular work of instruction as they constitute integral parts of the course and are attended not only by the graduate students but also by engineers from the city of New York and from nearby cities in the states of Connecticut, New Jersey, Pennsylvania, and New York.

The Davis library of highway engineering has been in constant use throughout the session. During some of the morning periods as many as 30 of our graduate students used the library at the same time. Our unequaled facilities in this field of engineering have proved of great value and are much appreciated by our graduate students and other engineers who wish to conduct library research in some field of highway engineering.

Sanitary Engineering.—The general development of the sanitary engineering course has already been noted. It may be further stated, however, that satisfactory results have been attained in all the subjects undertaken during the past year, so that they may be considered to have reached their full and permanent stage. As has been already indicated, however, the course on street cleaning and disposal of municipal wastes will not be realized in its complete proportions until next year. The department is fortunate in having secured the services of Mr. Tuska, who has had extended experience in this field of work and possesses the further qualification of having been an instructor in the Department in previous years.

The same interest is manifested by students outside the course in a number of the subjects given as was observed a year ago. Indeed, we are practically at the limit of our facilities for the number of students who have had to be accommodated during the year. Of the total number of 36 candidates for the degree of civil engineering, nine have taken the course in sanitary engineering, one-fourth of the total number.

Research Work.—Although considerable thesis research in plain and reinforced concrete has been done under expenditures from the income of the William R. Peters, Jr., Research Fund, there has been less than in the preceding year. The total expenditures on this account during the year, including some outstanding bills, was approximately $1500. It is advisable that a reserve amount should accumulate from time to time, as cumulative research is likely to arise at almost any time. It has been impossible, for instance, to begin the contemplated research on Poisson's ratio and other physical characteristics of structural materials, without the completion of original apparatus now in process of construction. A large amount of careful study has been given to this subject, and I hope and believe during the coming year a comparatively large amount of work can and will be done. There is also in contemplation a series of investigations in earth pressure against surfaces representing the backs of retaining walls, on a scale not before reached.

Testing Laboratory.—The work of the testing laboratory has been fully equal in amount during the current year to that done in any year heretofore, both in research and in commercial testing. In fact, considering the limited capacity of the machines, the results obtained in the laboratory are highly creditable.

WM. H. BURR.

Electrical Engineering.

During the past year the Department of Electrical Engineering has worked under a considerable handicap, for two reasons. First, we were deprived of the services of Professor Morecroft, whose serious illness kept him away from the department practically the whole second term. Second, due to peculiar political conditions, the contract between the City of New York and Columbia University, under which we have worked for many years, has been allowed to lapse.

Our principal aim during the past year has been to strengthen our course in radio-engineering, and to this end Prof. Morecroft, Mr. Parker, and a special mechanic have devoted the majority of their time. We have also spent a considerable portion of the departmental appropriation for necessary apparatus, which has been installed in the research laboratory of the Department of Electro-Mechanics. As our course in radio-engineering was on probation, as a result of Harvard's bid for this character of work, we have done everything in our power to strengthen the course. Prof. Morecroft's absence proved a serious handicap, but we were fortunate in securing the services of Mr. F. Lowenstein to give a series of 12 lectures, which he augmented voluntarily by a series of demonstrations in his own factory; the result has proved so satisfactory that I recommend that we endeavor to engage Mr. Lowenstein for at least a short series of lectures every year that we have naval officers with us. Mr. Lowenstein probably supplies more radio equipment to the navy than any other individual concern.

The equipment of our machine laboratories has been augmented by one motor-generator set consisting of a direct-current motor driving a polyphase alternating current generator in which each section of the winding is brought to an outside terminal bar, intended to demonstrate to the student the characteristics of any type of winding used in alternating-current machinery. We have also added to our laboratories one 3-hp. series motor, one 5-kvs. synchronous converter, one 3-hp. repulsion-induction motor, and a flicker photometer for our photo-metric laboratory. A high-potential oil-testing outfit has been donated to the laboratory by Mr. Mason.

City Contract.—During the last six months of 1914, under our contract with the City of New York, we tested nine meters and carried out five investigations. Since Jan. 1, we have had no contract with the City, but we have carried on a certain amount of work under an informal understanding with the Dept. of Water Supply, Gas and Electricity, which we hope will result in a renewal of the contract. During this time we have tested 18 meters and carried out one investigation. It is understood that in case the contract is not renewed we shall be paid for this work on a piece-rate basis. All this work has been carried out by Mr. Mason.

Personal.—Prof. Arendt has been appointed consulting engineer of the Municipal Service Commission, designated to take charge of all examinations for appointments in the fire-alarm and telephone service of the city. Prof. Arendt has also developed some new methods of electric arc welding, which have been put to commercial use. Prof. Slichter was one of the associate editors of the American Handbook for Electrical Engineers, which was published in the past year, contributing all the articles on the design of electrical machinery as well as a considerable portion of the material on electric railways.

Six naval officers registered with the Department of Electrical Engineering during the year, of whom four specialized in radio-engineering and two in electrical engineering. All these men completed their course satisfactorily, and plans have been agreed on with the post-graduate school at Annapolis by which these men will continue under the supervision of the officers of the Department of Electrical Engineering during the summer.

Mr. Elsasser E.E., 1914, who was appointed to the Trowbridge Fellowship last year, completed his very excellent work on the transmission of electrical energy through cables, and received the degree of M.A. His essay is very highly regarded by those who have read it, and he has secured a position with the American Telephone and Telegraph Co.

W. I. SLICHTER.

Geology.

The work of the Department of Geology progressed during the year in a successful and satisfactory way, with several incidents deserving of special mention.

The outbreak of the European war brought into special prominence the physiographic nature of the country over which the campaigns both in the East and West are being fought. Professor Douglas W. Johnson, who has been handling the physiographic side of the department's work, was quick to realize this relationship, and that it embraced many features of great interest to the University community and to our friends outside. In the endeavor to meet the opportunity, Dr. Johnson brought together last September the largest and most detailed maps available and organized an exhibit in the departmental library. Not only were the campaigns in western and eastern Europe shown, but also those at Tsing-tau in China, and in the colonial possessions in Africa. By world or continental maps, the naval battles, wherever occurring, were marked by pins. The collection of maps now accumulated for instruction in the department, those of the German and Austrian empires deposited formerly in the Deutsches Haus, and loans kindly made by the American Geographical Society, all aided in rendering the illustrations complete. Lines of worsted of contrasted colors were pinned to the maps and marked the advance and retreat of the operating forces. Both in the western and eastern campaigns, the geological structure has been the fundamental cause of the topographic relief, and therefore of the movements of the armies. By means of two large-scale, block diagrams, the one of France and Belgium, the other of Poland, Galicia and Hungary, these features were very clearly brought out.

Professor Johnson prepared a public lecture on the influence of the topography on the European campaigns, and after its presentation before the Institute of Arts and Sciences, and the New York Academy of Sciences, invitations to deliver it came from half a dozen other organizations in the City of New York, and from Vassar, Cornell, Rochester, Case Scientific School, Michigan, Wisconsin, and Johns Hopkins, as well as the American Philosophical Society, and several distinctive geographical organizations. In this respect Dr. Johnson has well served not only Columbia, but a wide circle of interested hearers elsewhere. His lectures have served greatly to strengthen physiography at Columbia and in the university world at large.

In outside service, Professor Grabau has been busied in the preparation of a report upon the palaeontology of the Devonian strata in the lower peninsula of Michigan, and before another year passes, plans to send to press this important scientific contribution.

Professor Berkey has continued his work for the New York Board of Water Supply and has recently been selected to take charge of a systematic compilation and report upon all the borings which have been made by departments of the city government and by private concerns in Greater New York. With the support of a special appropriation by the city, all the records are to be brought together and made available for reference in the future.

In the summer of 1914, Dr. Berkey, accompanied by C. N. Fenner, E.M. '93, Ph.D. '10, spent five weeks under the auspices of the New York Academy of Sciences in a reconnaissance of the geology of Porto

Rico. The New York Academy of Sciences, with the support of the Insular Government, and in association especially with the American Museum of Natural History, the New York Botanical Garden, and several educational institutions, including Columbia, has undertaken a five-year Natural History Survey of Porto Rico. The committee of the Academy having the matter in charge consists of N. L. Britton, Chairman, representing Botany; Franz Boas, Anthropology; H. A. Crampton, Zoology; J. F. Kemp Geology; and C. A. Poor, Oceanography. Dr. E. O. Hovey, as Secretary of the Academy, meets with the committee. In the course of five years, of which the first is just closing, reports are planned on all these subjects as affecting the Island. Professor Berkey, with the help of Dr. Fenner, who is now in the Carnegie Geophysical Laboratory in Washington, has prepared a very excellent preliminary outline of the geology, and has furnished a foundation whose details will be worked in, year by year.

Professor Kemp spent six weeks of the summer of 1914 in a study of the Mayari and Daiquiri iron-ore districts of Cuba. A paper on the former was published in the Bulletin of the American Institute of Mining Engineers for January, 1915, and one on the latter will appear during the current year. A paper on the "Outlook for Iron in the United States" has been prepared for the International Engineering Congress in San Francisco in September, 1915, in which the discussion of ore supply for the future is brought up to 1915. Two or three bulletins for the New York State Sociological Survey will be completed during the summer of 1915 on portions of the Adirondacks. The Commencement address at the Michigan College of Mines was delivered by Prof. Kemp in April. In February, 1915, at the annual meeting of the American Institute of Mining Engineers, Prof. Kemp was elected one of the twenty Honorary Members of the Institute. He was also reappointed chairman of the committee on mining geology.

In general, all the officers, and especially those of professorial rank, endeavor to keep in touch with geological and related work outside the University as well as in it, and through the New York Academy of Sciences, the American Geographical Society, the American Institute of Mining Engineers, the Mining and Metallurgical Society, the Geological Society of America, and other scientific and technical societies, to do our share in the general advancement of the science.

J. F. KEMP.

Mechanical Engineering.

With one exception, the staff of this department may be regarded as reasonably complete for the range of instruction required, and this long desired result has been consummated by the appointment of Professors F. O. Willhofft and L. DeG. Moss. There remains now only one appointment to complete the organization, that is, shop man, whom it is hoped can be secured next year. With this staff, not only can all the subjects be promptly presented to the present or prospective number of students, but the men composing this staff bring to the department abilities which are both complementary and supplementary. Each man represents some definite special branch of practice, beside being a general practitioner, and there is now for the first time a proper lapping over of these special abilities. This makes it possible for some one man in the department, with one or two exceptions, to take over, on emergency, the work of any other man, should this become necessary through resignation, illness, or leave of absence. In fact, the organization is such that the department is almost independent of any one man.

The probability that for a few years to come the number of students will be materially reduced, has made it seem unwise to retain the three salaried special lecturers on shop practice, compressors, and pumps, and these men have accordingly been dropped from the staff until such time as the student body may grow large enough to warrant

their return. In the meantime their subjects will be undertaken by the regular instructors, Professors Sleffel and Thurston, and Mr. Herrick, respectively.

During the past winter, Prof. Rautenstrauch visited several of the middle west and eastern colleges, and lectured on the subject of engineering as a career, for the purpose of pointing out the necessity for such training as our new course of study provides. The cordiality of his reception makes it seem wise for the University to undertake more of this sort of work on possibly a more elaborate scale. A somewhat similar message, though in a less formal way, was carried to the Pacific coast by Prof. Lucke, who visited San Francisco as Chairman of the Jury of Awards on Power Machinery at the Panama-Pacific Exposition, where he was the only representative of the eastern engineering schools, and had an opportunity to meet the representive engineers of the west coast and to discuss with them Columbia's ideals of engineering education. At the alumni reunion of this year, Prof. Moss presented a lecture on the contribution of mechanical engineers to the now pertinent topic of arms, armament and ammunition, which lecture he was requested to repeat several times both in and outside the University.

The year has seen the completion of three more text-books by the department, one on "Shop Practice" by Lecturer Halsey, a second on "Direct-Acting Pumps" by Lecturer Nickel, and the third an abridgement for short courses, by Professor Lucke and Professor Flather of Minnesota, of Prof. Lucke's "Engineering Thermodynamics." A further contribution to the literature has just been completed by Professors Parr and Thurston in their sections of the new "Mining Engineers' Pocketbook," edited by Professor Peele of the mining engineering department.

The second year of the department's relation with the Navy Department closed with even more satisfactory results than characterized the first year, and the feeling is growing more general that this relationship will be made permanent, a highly desirable situation from the standpoint both of the University and of the Navy.

Throughout the year a considerable amount of time has been devoted to the final modification of the new course of study, which is now reduced to a uniform schedule of 14 hours and five afternoons per week, and eight weeks required in the summer. The detailed planning of each of the courses of study has proceeded and it is expected that the results will be issued in printed form, giving a description of the subject matter in each period of instruction, in both condensed and extended form. The only bar to this program is the item of expense, which, however, seems justified in view of the clear benefits to be derived. Such detailed specifications will not only answer questions of prospective students of engineering as to the exact subject matter of instruction offered in our new course, as compared with other schools, but it will also crystallize the work of both student and instructor. Students will know, in starting a course, exactly what is to come and what is its relation to all other courses of instruction, which should contribute to rational and sustained interest in the subject. Instructors for the first time will know exactly what their associates are giving and at what time of the year, and can handle their own work and adopt their own methods accordingly.

This transition period from the old to the new standards for mechanical engineers involves many difficult problems. The most difficult one, which cannot be solved in a moment, is to make the new course properly serve the industries to which its graduates must look for employment, thus making the school contribute to the solution of their problems, not only by training men, but by improving processes and mechanisms.

While mechanical engineering is a profession as truly as any other, practically all of its practitioners must serve in some business and be as much business men as engineers. American engineering training in the past has, with some justification, been charged with the fault of

developing and fostering what may be termed "professional isolation." The success of the school in training men for the industries,, and conducting researches for industrial advancement and improvement, the success of the industries themselves and national prosperity itself, all demand the utmost intimacy of contact between the scientific man and the business man, between the school and the industrial establishments to a degree not heretofore known in this country. This is particularly true of the manufacturing and transportation industries, and as mechanical engineering is the technical basis of the industries, supplemented with electrical and chemical engineering, it seems proper that such modifications in our school as will contribute to the above end should be made. As the new course is about to start, no better time can be found than the present for doing this.

Accordingly it is proposed that the three departments, Mechanical, Electrical and Chemical Engineering, be drawn together to constitute a School of Manufactures and Transportation, having a separate faculty, with suitable representation from the departments of Economics, Sociology, and Law. This would place the work of these departments on a parallel with that of the School of Mines, industrially, and will facilitate the training of men for special industries such as railroading, central-station work, or any branch of manufacturing. It will also consolidate the research work of these departments in a manner commensurate with practice, where a problem of industrial importance involves all three branches of engineering in a manner so interwoven as to make separation impossible. This, as a first step, will go far in breaking down such lines of professional isolation as may now exist, and will build up direct lines of contact with the industries themselves, even the name of the school attracting attention and interest of those most concerned.

Attention has been called from time to time to the need of increased physical facilities in building and laboratory equipment not only for direct instruction but for research, and to the desirability of establishing these facilities in a proper clinical atmosphere by locating them in what might be called an industrial district. This need is just as real, though not so frequently recognized, as the need of hospital association with medical schools. By the consolidation of these three departments into a School of Manufacture and Transportation, new buildings will have to be provided for that school in an industrial locality on the water front, with railroad connections. This can be done at a cost very much less than would be required for the sort of buildings adapted to the present site. It is estimated that $100,000 would produce satisfactory building facilities, equal in every respect, except architecturally, to what would cost $400,000 on the present site, thus making available for actual working equipment the large difference of $300,000 involved.

With reference to research itself, nothing more than general plans have been formulated, as these plans must be based upon facilities now so inadequate. Such general ideas as have been developed have been communicated to the Committee on Instruction of the Faculty of Pure Science.

CHARLES E. LUCKE.

Metallurgy.

Organization.—The organization of the department has remained the same, and the present staff is able to handle the work in a satisfactory manner. No changes have been made in courses of instruction nor in the methods of giving these courses, although at the present time more attention is being given to conference on metallurgical subjects for students registered in metallurgical engineering.

A total of 25 courses were offered and students were registered in all of them, the total number of students being 273, a decrease of 11 compared with the previous year.

Teaching.—Instruction has been conducted in a satisfactory manner

during the year, and necessary changes have been made in all the lecture courses, so as to bring them up to date. Enlarged photographs are constantly being added to the collection, for the purpose of illustrating lectures on metallurgical subjects.

The course in practical metallography was again given to the naval officers from Annapolis in connection with their instruction in the engineering departments. In this work, stress is laid on the examination of faulty material used in marine work.

Research.—The extent of research work performed was somewhat less than usual, although several very interesting subjects were studied in our laboratories.

Summer Work.—The summer field work in metallurgy in 1914 consisted of visits to the various plants around New York, a careful inspection of the iron and steel plants in the vicinity of Pittsburg, and a trip through the West, including the metallurgical plants at Omaha, Denver, Colorado City, and Pueblo. The practice of showing the students the metallurgical plants around New York, under the direct supervision of an instructor, and then allowing them to proceed to Pittsburg and West in squads, has given such satisfaction that it will probably be continued.

Laboratories.—Few changes have been made in the laboratories during the past year, and the condition of these laboratories at the present time is such that the apparatus and the space required are ample for the present amount of instruction. The metallographic laboratory and the non-ferrous laboratory, which were equipped with new apparatus during 1913-14, have been found satisfactory, judging from the results obtained.

ARTHUR L. WALKER.

Mineralogy.

The necessary changes involved by the new six-year curriculum have been made and the old courses Mineralogy 1-2, Mineralogy 7-8, and Mineralogy 15-16 have been given for the last time. The new course (Mineralogy 14) in the College has been given during the past term. This course is designed to lay a broad foundation in mineralogy upon which it will be possible to develop more special courses, in economic mineralogy (Mineralogy 17) for the mining and metallurgical engineers, in crystallography and mineralogy (Mineralogy 10) for the chemists, and in optical mineralogy (Mineralogy 11) for the geologists and petrographers. Optical mineralogy (Mineralogy 11) is to be given throughout a whole term, instead of for half a term, the total number of hours remaining the same. There have been no essential changes made in the post-graduate courses for the degrees of A.M. and Ph.D.

The economic collection in the main museum has been enlarged to include the rarer minerals, which have recently become of economic importance. By using the lower drawers in these cases a large duplicate collection of labeled and numbered economic minerals has been built up, thus making it possible to study these minerals in relation to their localities and associates. By means of these new arrangements, students in the graduate courses will have unusual facilities for study. New conference collections have been arranged to meet the needs of the new courses.

A modern spectroscope and a chemical balance, for accurate specific gravity determinations, have been ordered. Very few new mineral species have been added during the year, as there has been no fund available for such purpose. The stock of more common student minerals, however, has been increased, so far as possible.

The recent publications have been:

"Microscopic Tests on Opaque Minerals," by Everend L. Bruce, School of Mines Quart., Vol. XXXV, No. 2, April, 1914. "Tables for

the Determination of Gems and Precious or Ornamental Stones without Injury to the Specimens", by Alfred J. Moses, School of Mines Quart., Vol. XXXVI, No. 3, April, 1915.

Professor Moses is enlarging his course in gem minerals and rewriting his text-book on general mineralogy.

L. McI. LUQUER.

Mining.

During the past year the instruction in mining has been seriously handicapped by the absence of the head of the department during the first-half, and of Professor Kurtz for the whole year. This threw a heavy burden on Professors Peele and Judd. During the first half-year, Mr. C. D. Clark, and his assistant, Mr. Wagner, gave "Mine Administration, Mine Accounting, and Mine Organization". Professor Judd gave the lectures in "Ore-dressing, the Mechanical Preparation of Coal, and Stamp Milling of Gold Ore."

On the return of the undersigned in the second half-year it was arranged that Professor Arnold, of the Law faculty, should give the course in mining law previously given by Professor Kurtz. While this course was an admirable one and ably presented, the arrangement was not altogether satisfactory for several reasons. The "case system" of instruction was used, which made excessive demands on the time of the students, out of all proportion to the importance of the subject, from an engineering standpoint. The subject was presented from the legal standpoint, and the difficulties of administering the law, owing to the impossibility of determining the geological facts, were ignored. Mining engineers and mining geologists who have to operate under the law are practically unanimous in asking for its revision. Finally, but little time was devoted to the mining law of other countries, of much importance to our graduates who find employment all over the world.

We were fortunate in obtaining the services of a number of outside lecturers in addition to those above enumerated. Mr. W. E. Gibbs, of the U. S. Bureau of Mines, described a new form of oxygen-breathing apparatus. Mr. Gibbs has been at work in the laboratory of this department for the past year, seeking to remedy the defects in the existing forms of breathing apparatus, and avoid the loss of valuable lives among the staff of the Bureau of Mines, due to these defects. The new design, resulting from the work of Mr. Gibbs, has been accepted by the Bureau of Mines, and arrangements are being made to manufacture the apparatus and equip the field forces of the Bureau. Mr. Gibbs is now engaged in designing an apparatus for manufacturing oxygen, which can be installed in the rescue car of the Bureau of Mines, for use of the rescue parties when called to the scene of mine explosions, mine fires, etc.

Mr. H. L. Mead (School of Mines, 1905), gave a lecture on hydraulic mining. Mr. R. V. Norris (School of Mines, 1885), gave three two-hour lectures on the testing of mine power plants, on mine accidents, and on the valuation of coal mines. Mr. Norris, with a large force of assistants, has been engaged for a year in determining the present value of the numerous mines of one of the largest anthracite corporations, so that his lecture on this subject was most interesting and valuable.

Mr. J. R. Finlay gave three lectures on the factors determining the cost of mining operations, and especially the effect of personality of men and managers on the result.

The number of students of mining for the past few years shows a steady decrease. This has happened several times in the history of the School of Mines, and is due to natural causes affecting the mining industry and the demand for the services of mining engineers. The mining industry is very sensitive to periods of financial stringency,—is perhaps the first to feel the effects and the last to recover. In addition to economic causes affecting the industry as a whole, our graduates

have suffered from the Mexican revolutions. Mexico has always required the services of a large number of American engineers; at the present time but few remain in that country. The European war, while stimulating the production of zinc and copper, will also act to prevent the employment of foreign capital in the search for the development of new mining properties, and another large field of employment for our graduates will be temporarily closed. For some years to come, the number of our mining students is likely to continue to diminish.

H. S. MUNROE.

BOOK REVIEWS

"The Magic of Jewels and Charms", by George Frederick Kunz, A.M., Ph.D., D.Sc., J. B. Lippincott Co., Philadelphia and London, 422 pp. with color plates and many other illustrations.

For many years Dr. Kunz has been assembling the folk lore, legends and descriptions of the strange uses made in different periods and countries of minerals and of curiously shaped stones, fossils and concretions. In 1913 he published a volume entitled "The Curious Lore of Precious Stones", dedicated to the late J. Pierpont Morgan. This year he has published as a companion volume "The Magic of Jewels and Charms", dedicated to the memory of the late professor Thomas Egleston, founder of the School of Mines of Columbia University, and until his death, professor of minerology and metallurgy in this school.

The plan of the book is best indicated by the ten chapter headings:

1. Magic stones and electrical gems.
2. Meteorites or celestial stones.
3. Stones of healing.
4. Virtues of fabulous stones, concretions and fossils.
5. Snake stones and bezours.
6. Angels and ministers of grace.
7. The religious use of various stones.
8. Amulets, ancient, medieval and Oriental.
9. Amulets of primitive peoples and of modern times.
10. Facts and fancies about precious stones.

The book will be read with pleasure by lovers of folk lore and the mineralogist will gather from it many interesting details not generally available.

A. J. Moses.

"Theory of Measurements." By J. S. Stevens. Cloth 5x7 in.; 81 pp. D. Van Nostrand Co., New York. 1915. Price $1.25.

To give an adequate treatment of the theory of measurements in 80 pages is a very difficult task. Professor Stevens' little book gives one the impression of being a series of good lecture outlines rather than a text-book for use of students. Though the preface contains the statement "A 'rule of thumb' knowledge——is not to be recommended", it seems to the reviewer that this is all that the average student, approaching the subject for the first time, can possibly hope to obtain from this book. The numerous references to standard texts on least squares and precision of measurements lead one to ask why the student should not go to them at once for all his guidance.

W. W. Stifler.

"Wireless Telegraphy" by J. Zenneck; translated from the German by A. E. Seelig. 443 pp.; 461 figures, XIII tables. McGraw-Hill Book Co., New York, 1915. Price $2.60.

The translator of Zenneck's "Lehrbuch der drahtlosen Telegraphie" has performed a very valuable service in making this authoritative text accessible to the student not having command of technical German. During the last three years the reviewer has used the German edition as a reference book for his students in radio work, and has found it a very fruitful source of information.

The text contains theoretical discussions of circuits and machines as well as descriptions of construction and operation of machines and apparatus from the practical standpoin. It is really an abbreviation of the same author's more pretentious volume entitled "Electromagnetische Schwingungen und drahtlose Telegraphie", which has been the most thorough text on wireless telegraphy obtainable since its publication in 1905. The larger volume has not yet been translated into English, and it seems likely that the student of Seelig's translation of the shorter text will frequently be in difficulty because he cannot consult the larger volume for the derivation of some of the formulas, the derivations in the English text being very meagre and sometimes lacking altogether. Some of the figures are also described so briefly that it is difficult to understand them.

Because of the inaccessibility of the larger text, the translator would have done well to fill in those parts where the treatment is too brief, but he has instead given a very literal translation, preferring, so he says in the preface, to "let Zenneck be Zenneck". This has been carried to such an extent that we see some very strange expressions, for example, "the currentlessness of a circuit".

The original text was published in 1909, and in 1912 when the second edition appeared a few pages only were added; hence the present translation really gives the art as it existed in 1909. In six years the art has made very great progress; the student must, however, consult the various periodicals for all the developments during that time, as they are not given in the text.

In spite of the shortcomings mentioned above the text should at once find a place in the library of every student of wireless telegraphy; after mastering some of the more elementary texts on the subject Zenneck's will be found of inestimable value.

J. H. MORECROFT.

ALUMNI NOTES.

1878. Dr. Marcus Benjamin, editor for the United States National Museum in Washington, has received a silver medal for his exhibition of portraits and autograph letters of the presidents of the American Association for the Advancement of Science.

1892. Henrich Ries, Ph.D., head of the department of geology at Cornell University, was engaged during the past summer in examining the clay resources of Virginia for the geological survey of that state. A new and revised edition of Ries and Watson's "Engineering Geology" is now being published by Wiley and Sons.

1894. Harris K. Masters, E.M., is connected with the Remington Arms and Ammunition Co., at their new works at Bridgeport, Conn.

1896. Ambrose Monell, E.M., is one of the directors of the new Midvale Steel Co.

1896. E. M. Sergeant, E. E., is general manager of the Niagara Alkali Co., of Niagara Falls, N. Y.

1896. L. V. Emanuel, E.M., is with the River Smelting and Refining Co., at Florence, Colo.

1897. On Sept. 15, 1915, there was born to Mr and Mrs. James Ellwood Jones, Switchback, W. Va., a daughter, Nancy Walton.

1900. O. B. Perry, E.M., on Nov. 18, 1915, delivered a lecture at the School of Mines on the subject of gold dredging, a matter in which he has become expert through his connection with the Yukon Gold Co.

1901. Charles E. Morrison, C.E., and Orrin L. Brodie, C.E., are revising their book on "High Masonry Dam Design," which will shortly be published by John Wiley & Sons.

1902. Henry F. Haviland, E.E., of the firm of Walker Brothers and Haviland, announces that the offices of the firm are now located in the Peoples Gas Building, 122 South Michigan Avenue, Chicago.

1902. Frederick B. Irvine, E. M., is with the Morgan Engineering Co., at Dayton Ohio, engaged in flood prevention work.

1903. F. B. Clark, formerly with the Remington Arms Co., is now second vice-president of the Robin Hood Ammunition Co., at Swanton, Vt.

1903. S. F. Shaw, E. M., has been put in temporary charge of the American Smelting and Refining Company's Dairy Farm mine at Van Trent, Cal., pending the settlement of disorder at Charcas, San Luis Potosi, where he has been manager.

1904. Lucius W. Mayer, E.M., has severed his connection with A. Chester Beatty, '98, with whom he has been

associated for the past seven years, and is now associated with Eugene Meyer, Jr., & Co.

1904. Elihu Canyngham Church, C.E., was married on Nov. 24, 1915, to Mrs. Clare Southmayd De Harte, of Elizabeth, N. J. Church at one time was secretary of the Department of Water Supply, Gas and Electricity.

1905. C. N. Nelson, E.M., for several years on the staff of the New York and Honduras Rosario Mining Co., at San Juancito, Honduras, was lost in the wreck of the United Fruit Company's steamer, "Marowjine," in the Gulf of Mexico last August. He was accompanied by his fiancee to whom he expected to be married on arriving in the United States.

1905. Reginald G. Kinsey, E.M., is lieutenant in the Second Battalion Highland Light Infantry and is located with the British expeditionary force in France.

1905. Carl H. Decker, E.M., who for the past four years has been superintendent and engineer for the Cubo Mining and Milling Co., at Guanajuato, Mexico, is visiting New York. Henry L. Hollis, '85, of Chicago is president of the company.

1906. H. C. Enos, E.M., has recently returned from Central America, and will spend several weeks in Utah.

1906. Otto Kress, Ph.D., has been placed in charge of the paper and pulp section of the Forest Products Laboratory, at Madison, Wis.

1908. Rush G. Estee, E.M., is the head of the firm of R. G. Estee & Co., a stock exchange firm, with offices at 52 Broadway, New York City.

1908. E. W. Startwout, Mech.E., formerly manager of the Nordberg Manufacturing Company's Chicago office, has been tranferred to the New York office as mechanical engineer.

1909. George B. Holderer, E.M., who recently returned from South America, has been made general manager of the Furlough Development Co., which is developing a copper mine near Wickenburg, Ariz.

1909. On Nov. 15, 1915, in London, England, a son, Everett Weston, was born to Mrs. and Mr. Robert Annan.

1909. E. B. Latham, E.M., is deputy state oil and gas supervisor with the department of petroleum and gas of California State Mining Bureau, located at First National Bank Building, Santa Maria, Santa Barbara Co., Cal.

1910. Mr. and Mrs. M. H. Merriss, North Avenue and Chilham Road, Mt. Washington, Md., announce the birth of a son, Geoffrey, on Oct. 20, 1915, in Baltimore. Merriss is a metallurgical engineer at the American Smelting and Refining Company's copper refinery in Baltimore.

1910. M. D. Malcomson is now employed as research chemist with the Pittsburgh Testing Laboratory.

1911. Alfred L. Jaros, Mech.E., and Albert L. Baum, Mech.E., have formed a partnership for the practice of power engineering and ventilation. Address: Webster Avenue and East River, Long Island City.

1911. A son was born on Dec. 15, 1915, to Mr. and Mrs. Wyman Drummond Herbert, 619 West 127th Street, New York.

1911. J. M. Hoffman, E.M., who is with the Companie Forminiere at Tshikapa, Kasai, Belgian Congo, is reported to have recovered from an operation for appendicitis at Luebo.

1911. Montrose L. Lee, E.M., who has been with the National Mining Bureau of Uraguay under M. A. Lamme, '04, recently left South America for Bordeaux, intending to spend a few months in France and Spain.

1911. Percy R. Iseman, E.M., is a member of the firm of Edgar A. Levy Construction Co., whose offices are at 505 Fifth Avenue, New York City.

1911. Mr. and Mrs. Joseph Morris Murray, 436 Convent Avenue, New York, announced the birth of a son, Robert Hamilton, on July 16, 1915.

1912. Edward B. Hinman, Jr., E.M., has resigned his position with the Granby Company, in British Columbia, where he has been for three years.

1912. Milton D. Schwartz, E.M., is connected with the T. A. Gillespie Co., with offices in the Westinghouse Building, Pittsburg, Pa.

1913. N. B. Gatch, E.M., superintendent of the Granby, Missouri, plant of the Granby Mining and Smelting Co., recently visited New York on his way to study ore flotation as practised at Mascot, Tenn.

1913. Richard P. Grieve, E.M., is on the engineering staff of the Public Service Commission, his work being at Shaft No. 3 of the East River tunnels.

1913. D. G. Campbell, E.M., has been engaged by the Tacoma Smelting Co., to investigate troubles with their sampling operations.

1913. On Nov. 10, 1915, Paul Bissell Covey, C.E., was married to Miss Elizabeth Hopkins in Brattleboro, Vt. Covey is connected with the American Bridge Co., and will live in Ambridge, Pa.

1913. Arthur H. Kohlbusch was married on Nov. 6, 1915, to Miss Margaret Elizabeth, daughter of Mr. and Mrs. Harry Jared Ketcham, of Passaic, N. J.

1913. W. Carruthers, E.M., is with the Lehigh Coal and Navigation Co., as assistant general superintendent of the Coaldale District. J. Miller, E.M., '14, is assistant superintendent of the Nesquehoning District for the same company, and H. S. Rade is assistant superintendent to the preparation department.

1913. D. G. Hubbard, E.M., who is connected with the Copper Queen Co., at Morenci, Ariz., spent his vacation in New York in October.

1913. Henry Tackmann, E.M., is connected with the Granby Mining and Smelting Co., at Granby, Mo.

1913. G. F. Schattinger, E.M., who for two years has been in charge of construction work at Chuquicamata, Chile, returned to New York in October, 1915.

1913. E. Newhouse, Met. E., and R. W. Hyde, Met.E., are engaged in experimental work in electrometallurgy of zinc with the American Smelting and Refining Co., at Murray, Utah.

1914. W. F. Maul, E.M., has gone to assist A. H. Morrill, E.M., '13, in the engineering of the Central Chili Copper Co., at Coquimbo.

1914. James T. Beard, Jr., is installing a mechanical stoker system in the power plant of the Mathieson Alkali Works at Saltville, Va., for the Combustion Engineering Corporation of this city. His father, James T. Beard, '77, is senior associate editor of Coal Age.

1914. Roy U. Wood, Met.E., who has been until recently connected with the American Smelting and Refining Company's plant at Perth Amboy, N. J., has gone to that company's smelter at Garfield, Utah, which is known as the Garfield Smelting Co.

1914. John Cornelissen, E.M., is in the construction department of the Aetna Explosive Co., at Mount Union, Pa.

1914. S. E. Woodworth, Met.E., has gone into partnership with E. M. Hamilton and F. A. Beauchamp, metallurgical enigineers, specializing in flotation and cyniding. 419 The Embarcadero, San Francisco, Cal.

1914. Latest reports from the front indicate that W. W. Colquhoun, Met.E., is a prisoner of war , held by the Germans. The last word that was received from him was about Sept. 25, stating that he was fighting in the battle of Loos. He was reported missing the following day and it is now believed that he has been captured. Colquhoun is a captain in the Scottish Light Horse and had just returned to the front after recovering from a wound received in northern France.

DENIAL

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DATE DUE	BORROWER'S NAME

IN U. S. A.